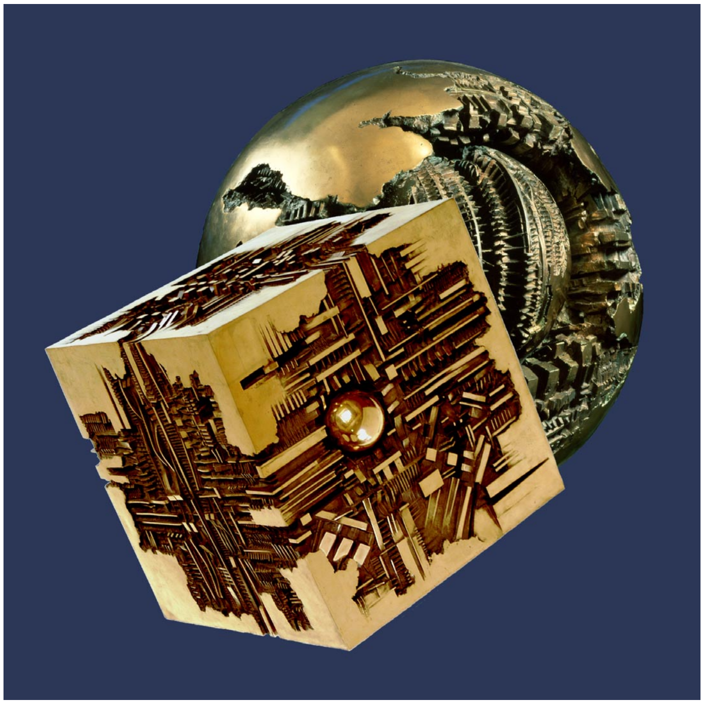
Helioseismic and Magnetic Imager
for
Solar Dynamics Observatory



HMI Science Plan
Including Science Requirements

SU-HMI-S014

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Stanford University Hansen Experimental Physics Laboratory
and
Lockheed-Martin Solar and Astrophysics Laboratory

The cover of the NASA 1984 report "Probing the Depth of a Star: The Study of Solar Oscillations from Space" featured Hirschhorn's the Pomodoro Sphere. That report led to the helioseismic study of the global Sun. Pomodoro's Cube at Stanford symbolizes HMI data cubes for investigation of localized regions in the Sun.

HMI Science Investigation Plan

Contents

1 Overview

The primary goal of the Helioseismic and Magnetic Imager (HMI) investigation is to study the origin of solar variability and to characterize and understand the Sun's interior and the various components of magnetic activity. The HMI investigation is based on measurements obtained with the HMI instrument suite as part of the Solar Dynamics Observatory (SDO) mission. HMI makes measurements of the motion of the solar photosphere to study solar oscillations and measurements of the polarization in a spectral line to study all components of the photospheric magnetic field. HMI produces data to determine the interior sources and mechanisms of solar variability and how the physical processes inside the Sun are related surface magnetic field and activity. It also produces data to enable estimates of the coronal magnetic field for studies of variability in the extended solar atmosphere. HMI observations are crucial for establishing the relationships between the internal dynamics and magnetic activity to understand solar variability and its effects, leading to reliable predictive capability, one of the key elements of the LWS program. The HMI investigation directly addresses and assists the highest priority science goals of SDO.

The HMI investigation includes the following elements:

- The HMI instrument is a suite encompassing the observing capabilities required to complete the combined 'HMI' and 'HVMI' objectives as described in the SDO Announcement of Opportunity. The instrument has significant heritage from the Solar and Heliospheric Observatory (SOHO) Michelson Doppler Imager (MDI) with modifications to allow higher resolution, higher cadence, and the addition of a second channel to provide polarization measurements. HMI provides stabilized 1"-resolution full-disk Doppler velocity and line-of-sight magnetic flux images every 44 seconds, and vector-magnetic field maps every 88 seconds. The HMI instrument will be provided by Lockheed-Martin Solar and Astrophysics Laboratory (LMSAL) as part of the Stanford Lockheed Institute for Space Research collaboration.

- The significant data stream to be provided by HMI must be analyzed and interpreted with advanced tools that permit interactive query of the complex flows and structures deduced from helioseismic inversion. It will be essential to have convenient access to all data products - Dopplergrams, full vector magnetograms, subsurface flow fields and sound-speed maps, as well as coronal field estimates - for any region or event selected for analysis. This investigation will provide a data system for archiving the HMI data and derived data products with convenient access to the data by all interested investigators. Sufficient computing capability will be provided to allow the complete investigation of a set of the HMI science objectives. The HMI investigation includes support of integration of HMI onto SDO, mission planning, HMI operations and receipt and verification of HMI data.

- Some of the higher level HMI data products are likely to be of use in monitoring and predicting the state of solar activity. Such products are identified in Phase-A and produced on a regular basis at a cadence appropriate for each product.

- HMI will obtain filtergrams in various positions in a spectral line and polarizations at a regular cadence for the duration of the mission. Several higher levels of data products will be produced from the filtergrams. The basic science observables are full-disk Doppler velocity, brightness, line-of-sight magnetic flux, and vector magnetic field. These will be available on request at full resolution and cadence. Of more interest are sampled and averaged products at various resolutions and cadence and sub-image samples tracked with solar rotation. A selection of these will be made available on a regular basis, and other data products will be made on request. Also of great potential value are derived products such as sub-surface flow maps, far-side activity maps, and coronal and solar wind models which require longer sequences of observations. A selection of these will also be produced in the processing pipeline in near real time. A number of the HMI Co-Investigators (Co-Is) have specific roles in providing software to enable production of these higher level products.

- This plans identifies a broad range of science objectives that can be addressed with HMI observations. HMI provides a unique set of data required for scientific understanding, detailed characterization and advanced warning of the effects of solar disturbances on global changes, space weather, human exploration and development, and technological systems. HMI also provides important input data required for accomplishing objectives of the other SDO instruments. The HMI investigation will carry out a number of the highest priority studies throughout to publication of the results and presentation to the scientific community.

- SDO investigations and HMI in particular have aspects which will be of great interest to the public at large. Also SDO and HMI will

- Offer excellent opportunities for developing interesting and timely educational material. A highly leveraged collaborative Education and Public Outreach (E/PO) program is a key part of this investigation.

The Science Objectives presented include long-standing problems in solar physics as well as questions which have developed in response to recent progress. The investigation builds on the current knowledge of the solar interior, photosphere, and atmosphere, recent space- and ground-based programs, and advances in numerical modeling and theoretical understanding. The helioseismic and line-of-sight magnetic flux measurements provide the key data required for the core HMI science program to characterize and understand the Sun’s interior and various components of magnetic activity. The HMI capability to measure the vector magnetic field strengthens the program tremendously, in particular, for studying magnetic stresses and current systems associated with impulsive events and evolving magnetic structures.

The HMI science program has evolved from the highly successful programs of MDI, Global Oscillation Network Group (GONG) and Advanced Stokes Polarimeter (ASP). The Co-Investigators includes leading experts in helioseismic and magnetic field measurements, experienced instrument developers, observers, mission planners, theorists, and specialists in numerical simulations, data processing and analyses.

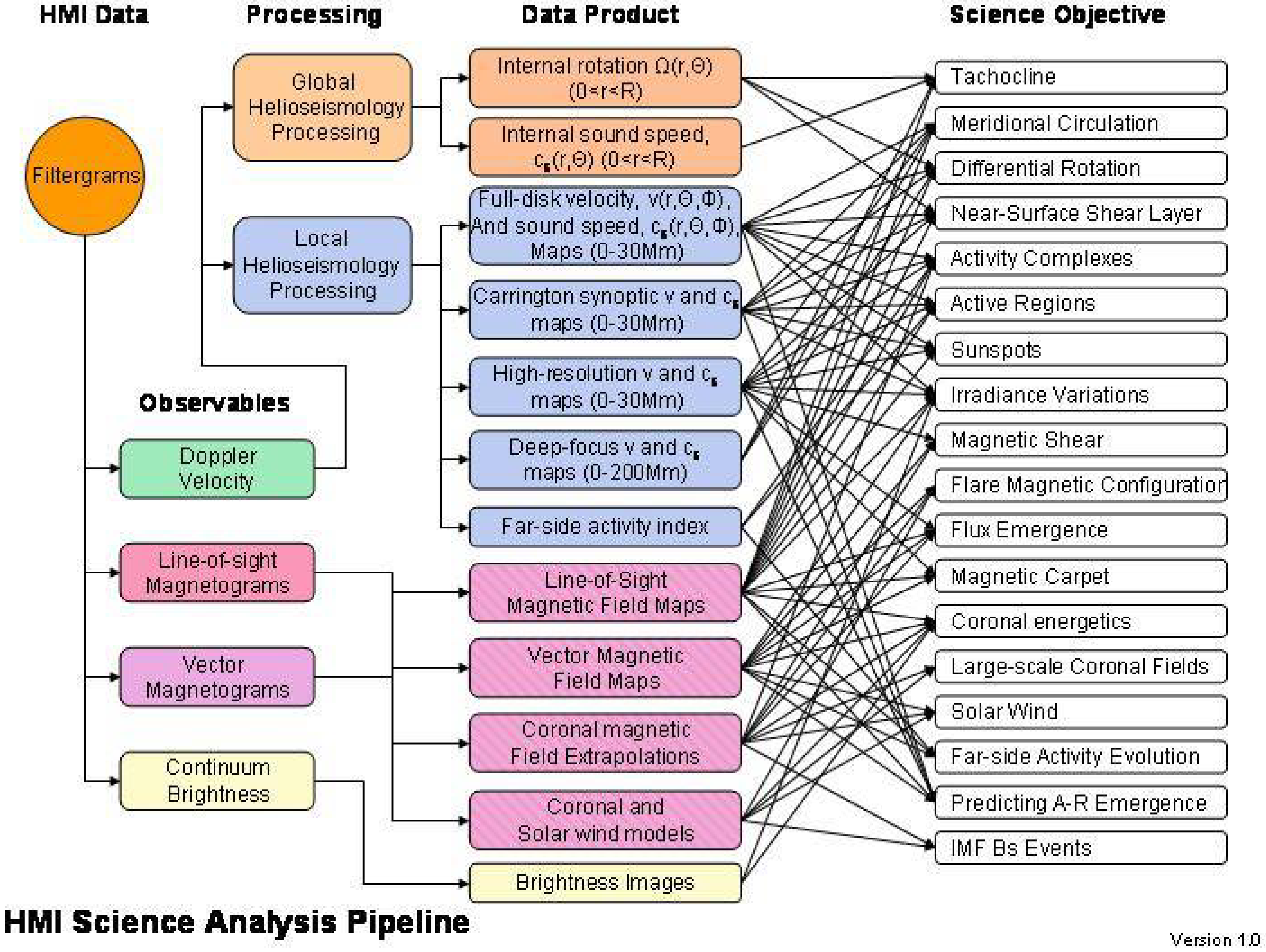

Figure 1 HMI Science Analysis Pipeline

2 Scientific Goals and Objective

The HMI investigation encompasses three primary LWS objectives: first, to determine how and why the Sun varies; second, to improve our understanding of how the Sun drives global change and space weather; and third, to determine to what extent predictions of space weather and global change can be made and to prototype predictive techniques.

2.1 Science Overview

The Sun is a magnetic star. The high-speed solar wind and the sectoral structure of the heliosphere, coronal holes and mass ejections, flares and their energetic particles, and variable components of irradiance are all linked to the variability of magnetic fields that pervade the solar interior and atmosphere. Many of these events can have profound impacts on our technological society, so understanding them is a key objective for LWS. A central question is the origin of the solar magnetic fields. Most striking is that the Sun exhibits 22-year cycles of global magnetic activity involving magnetic active region eruptions with very well defined polarity rules[1] resulting in global scale magnetic patterns. Coexisting with these large-scale ordered magnetic structures and concentrated active regions are ephemeral active regions and other compact and intense flux structures that emerge randomly over much of the solar surface forming a 'magnetic carpet'[2, 3]. The extension of these changing fields at all scales into the solar atmosphere creates coronal activity which in turn is the source of geospace weather variability. The HMI science investigation addresses the fundamental problems of solar variability with studies in all interlinked time and space domains, including global scale, active regions, small scale, and coronal connections. One of the prime objectives of the Living With a Star program is to understand how well predictions of evolving space weather variability can be made. The HMI investigation will examine these questions in parallel with the fundamental science questions of how the Sun varies and how that variability drives global change and space weather.

The tools that will be used in the HMI program include: helioseismology to map and probe the solar convection zone where a magnetic dynamo likely generates this diverse range of activity; measurements of the photospheric magnetic field which results from the internal processes and drives the processes in the atmosphere; and brightness measurements which can reveal the relationship between magnetic and convective processes and solar irradiance variability.

Helioseismology, which uses solar oscillations to probe flows and structures in the solar interior, is providing remarkable new perspectives about the complex interactions between highly turbulent convection, rotation and magnetism. It has revealed a region of intense rotational shear at the base of the convection zone[4-6], called the tachocline[7, 8], which is the likely seat of the global dynamo[9-11]. Convective flows also have a crucial role in advecting and shearing the magnetic fields, twisting the emerging flux tubes and displacing the photospheric footpoints of magnetic structures present in the corona. Flows of all spatial scales influence the evolution of the magnetic fields, including how the fields generated near the base of the convection zone rise and emerge at the solar surface, and how the magnetic fields already present at the surface are advected and redistributed. Both of these mechanisms contribute to the establishment of magnetic field configurations that may become unstable and lead to eruptions that affect the near-Earth environment.

New methods of local-area helioseismology have begun to reveal the great complexity of rapidly evolving 3-D magnetic structures and flows in the sub-surface shear layer in which the sunspots and active regions are embedded. Most of these new techniques were developed by members of the HMI team during analysis of MDI observations. As useful as they are, the limitations of MDI telemetry availability and the limited field of view at high resolution has prevented the full exploitation of the methods to answer the important questions about the origins of solar variability. By using these techniques on continuous, full-disk, high-resolution observations, HMI will enable detailed probing of dynamics and magnetism within the near-surface shear layer, and provide sensitive measures of variations in the tachocline.

Just as existing helioseismology experiments have shown that new techniques can lead to new understanding, methods to measure the full vector magnetic field have been developed and shown the potential for significantly enhanced understanding of magnetic evolution and connections. What existing and planned ground based programs can not do, and what Solar-B can not do is to observe the full-disk vector field continuously at a cadence sufficient to follow activity development. HMI vector magnetic field measurement capability, in combination with the other SDO instruments and other programs (e.g. STEREO, Solar-B, and SOLIS) will provide data important to connect solar variability in the solar interior to variability in the solar atmosphere, and to the propagation of solar variability in the heliosphere.

HMI brightness observations will provide information about the area distribution of magnetic and convective contributions to irradiance variations, and also about variations of the solar radius and shape.

2.2 Primary Science Objectives

The broad goals described above will be addressed in a coordinated investigation of a number of parallel studies. These segments of the HMI investigation are to observe and understand these interlinked processes:

- Convection-zone dynamics and the solar dynamo;
- Origin and evolution of sunspots, active regions and complexes of activity;
- Sources and drivers of solar activity and disturbances;
- Links between the internal processes and dynamics of the corona and heliosphere;
- Precursors of solar disturbances for space-weather forecasts.

These goals represent long-standing problems which can be addressed by a number of more immediate tasks. The description of these tasks reflects our current level of understanding and will obviously evolve in the course of the investigation. Some of the currently most important tasks are described below and summarized in Table 1.

Table 1. HMI Science Objectives

HMI Science objectives	Main Tasks	Specific Goals	Technical Approach and Methodology	Science Data Requirements	Co-I Teams	Required resources
Convection zone dynamics and solar dynamo	Structure and dynamics of the tachocline	a) the shape and thickness of the tachocline and variation with the solar cycle; b) the latitudinal structure of zonal tachocline flows; c) longitudinal variations of the tachocline structure and flows; d) relationship between the tachocline dynamics and magnetic activity	1)global helioseismology: medium-l mode analysis 2)time-distance helioseismology: deep-focus maps 3)acoustic holography: local variations of reflection properties of the tachocline	1)72-day series of Dopplergrams; 2)24-hour continuous Dopplergram series, 6-day tracking Data sets: HS-1, HS-2, MAG-1	1)R.Howe, R. Komm, J. Schou 2)T.L. Duvall, Jr, A..G.Kosovichev, A.C. Birch 3)D.C. Braun, C.Lindsey	HMI and LWS grants + additional support for holography (1 FTE)
	Variations in differential rotation	a) differential rotation of near polar regions, and variations with activity b)the origin of 'torsional oscillations' c)the driving mechanism of the differential rotation and turbulence properties	1)global helioseismology: inversion of mode frequency splitting including high-degree modes 2) local helioseismology (rings and time-distance): patterns of differential rotation in the flow synoptic maps; 3) inverse modeling and data assimilations: 3D numerical simulations and data nudging	1)72-day series of Dopplergrams; 2)24-hour time continuous Dopplergram series, 9-day tracking 3) 90-day continuous Dopplergrams twice per year Data sets: HS-1, HS-2, HS-3, MAG-1	1)R.Howe, R. Komm, J. Schou 2)T.L. Duvall, Jr, A..G.Kosovichev, A.C. Birch, L. Gizon 3)J.Toomre, R. Bogart, F. Hill 4)N.Mansour, A.Wray, M.Miesch	HMI + additional support for modeling and data assimilation tasks (2 FTE) and for the ring-diagram analysis (1 FTE)

	Evolution of meridional circulation	a) The latitudinal and depth dependencies of the meridional flow b) The depth and speed of the reverse flow c) The existence of multiple meridional circulation cells d) The effects of the activity belts and active regions on the latitudinal structure and speed of meridional flows e) The longitudinal dependence of the meridional flows, and their relation with active longitudes	1) Local helioseismology based on the ring-diagram analysis and time-distance technique. The time-distance analysis will employ two approaches: i. averaging the North-South component of synoptic flow maps ii. directly measuring the mean North-South reciprocal travel times and the corresponding velocity component. 2) Correlation tracking of magnetic structures 3) Data modeling and assimilation using 3D numerical simulations	1) 24-hour time continuous Dopplergram series, 9-day tracking 2) 90-day continuous Dopplergrams twice per year 3) full-disk magnetograms, two 90-day periods per year Data sets: HS-2, HS-3, MAG-1	1) J.Toomre, R. Bogart, F. Hill R.Howe, R. Komm, J. Schou 2) T.L. Duvall, Jr, A..G.Kosovichev, A.C. Birch, L. Gizon, J.Zhao 3) N. Mansour, A.Wray, M.Miesch	LWS, HMI + additional support for modeling and data assimilation tasks (2 FTE) and for the ring-diagram analysis (1 FTE)+ super-computer resources
	Dynamics in the near surface shear layer	a) Mean stratification and thermodynamic properties, testing the equation of state b) Structure and dynamics of supergranulation, the depth of the reverse flow, mass, energy and momentum transport c) Variations of the subsurface shear flow with latitude and time d) Distribution of kinetic helicity and relation to large-scale magnetic patterns e) Excitation and damping of p- and f-modes, waves-turbulence interaction f) Understanding convective energy transport and role in irradiance	1) High-degree global helioseismology: inversion of frequencies and frequency splitting of p- and f-modes of l=200-1000 to infer the subphotospheric rotation rate, sound-speed asphericity, and thermodynamic properties (adiabatic exponent and other properties of the equation of state; 2) Local helioseismology: synoptic flow and sound-speed maps 3) F-mode helioseismology (global and local) 4) Correlation analysis between flows and magnetic fields 5) Numerical simulations and data assimilation	1) 90-day continuous Dopplergrams twice per year 2) full-disk magnetograms, two 90-day periods per year Data sets: HS-3, MAG-1	1) E. Rhodes, J. Reiter 2) T.L. Duvall, Jr, A..G.Kosovichev, A.C. Birch, L. Gizon, J.Zhao, Y.Liu 3) J.Toomre, R. Bogart, F. Hill R.Howe, R. Komm, J. Schou 4) N. Mansour, A.Wray, M.Miesch	Support for Johann Reiter + additional support for modeling and data assimilation tasks, inversion analysis (1 FTE), and tasks e) and d) (1FTE)+ super-computer resources

Origin and evolution of sunspots, active regions and complexes of activity	Formation and deep structure of magnetic complexes of activity	a) Relationship between large-scale flow patterns and magnetic flux emergence; b) Impulses of solar activity and large-scale dynamics; c) Search for thermal shadows in the interior	1) Deep-focus synoptic flow and sound-speed maps from time-distance helioseismology and acoustic holography 2) Analysis of near-surface flow and sound-speed maps 3) Correlation analysis of the helioseismic and magnetic data	1) 24-hour time continuous Dopplergram series, 9-day tracking 2) 120-day continuous Dopplergrams, one period per year 3) full-disk magnetograms, two 90-day periods per year Data sets: HS-2, HS-4, MAG-1, IC-1	1)T.L. Duvall, Jr, A.G. Kosovichev, J.Zhao, T.Hoeksema, E.E.Benevolenskay 2)J.Toomre, R. Bogart, F. Hill R.Howe, R. Komm, J. Schou	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)
	Active region source and evolution	a) Tracking the lifecycle of selected active regions (emergence, evolution, decay) b) Detection of emerging flux in the interior c) Relationship between large-scale flow patterns and stability of active regions d) Search for signatures of disconnection of magnetic flux from deep interior structures e) The depth of the circulation flow around active regions f) How active regions affect the structure and speed of meridional flows g) The role of magnetic reconnections in the corona for the evolution of active regions h) Submergence of magnetic flux	1) Local helioseismology of selected active regions with 8-hour resolution (deep and surface focusing schemes) 2) Time-distance analysis of emerging active regions for 2-hour intervals 3) Relationship between the synoptic flow patterns and local flows around active regions 4) Correlation between the internal flows and sound-speed perturbations and photospheric field 5) Connectivity of active regions in the corona and their evolution	1) 24-hour time continuous Dopplergram series, 9-day tracking 2) 12-day continuous Dopplergrams, 20 periods per year 3) full-disk magnetograms, twenty 12-day periods per year 4) coronal EUV images Data sets: HS-2, HS-5, MAG-3	1)T.L. Duvall, Jr, A..G.Kosovichev, J. Zhao, S.Couvidat, E.E.Benevolenskaya, Y.Liu,T.Hoeksema 2)J.Toomre, R. Bogart, F. Hill R.Howe, R. Komm, J. 3) C.Lindsey, D.C. Braun	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE

	Magnetic flux concentration in sunspots	a) Relationship between the flow dynamics and flux concentration in sunspots b) The relation between the Evershed effect and deep flow pattern c) Determination of the relative role of temperature and magnetic perturbations in the sound-speed images d) Relation between the internal vortex flows, magnetic twists of sunspots and coronal activity e) Connectivity between sunspots in active regions f) Prediction of lifetime of sunspots by observing the internal circulation	1) Local helioseismology of selected active regions with 8-hour resolution (deep and surface focusing schemes) 2) Time-distance analysis of rapidly growing sunspots for 2-hour intervals 3) Relationship local flows around sunspots, magnetic field, and EUV loop structures 4) Numerical modeling and data assimilation	1) 24-hour time continuous Dopplergram series, 9-day tracking12-day continuous Dopplergrams, 20 periods per year 2) full-disk magnetograms, twenty 12-day periods per year 3) coronal EUV images Data sets: HS-2, HS-5, MAG-3	1) T.L. Duvall, Jr, A..G.Kosovichev, J. Zhao, S.Couvidat 2) J.Toomre, R. Bogart, F. Hill R.Howe, R. Komm, J. 3) C.Lindsey, D.C. Braun 4) N. Mansour, A.Wray,	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (2 FTE) + super-computer resources
	Sources and mechanisms of solar irradiance variations	a) Relationship between magnetic flux and the total irradiance b) Effects of magnetic features on UV spectral irradiance c) Relationship between the subphotospheric dynamics and irradiance variations	1) Semi-empirical models for solar irradiance 2) Local helioseismology of selected magnetic regions with 8-hour resolution (deep and surface focusing schemes)	1) 24-hour time continuous Dopplergram series, 9-day tracking12-day continuous Dopplergrams, 20 periods per year 2) full-disk magnetograms, twenty 12-day periods per year 3) coronal EUV images Data sets: HS-2, HS-5, MAG-3	1) S.Solanki, Y.Liu, A.G.Kosovichev, P.H.Scherrer	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)

HMI Science objectives	Main Tasks	Specific Goals	Technical Approach and Methodology	Science Data Requirements	Co-I Teams	Required resources
Sources and drivers of solar activity and disturbances	Origin and dynamics of magnetic sheared structures and delta-type sunspots	a) relationship between subphotospheric flows and formation of delta-type sunspots and sheared magnetic structures b) emerging flux and magnetic helicity in delta-spots c)relationship between the subphotospheric dynamics and activity	1) Time-distance analysis of delta-type sunspots for 2-hour intervals 2) Correlation tracking of magnetic elements 3)Non-linear force-free magnetic field reconstruction 4)Relationship local flows around sunspots, magnetic field, and EUV loop structures	1)24-hour time continuous Dopplergram series, 9-day tracking; 12-day continuous Dopplergrams, continuum images for at least 5 sunspots 2)full-disk magnetograms 3)coronal EUV images Data sets: HS-8, MAG-4,IC-2	1)A.G.Kosovichev, T.L. Duvall, Jr., J. Zhao, Y.Liu, T.Hoeksema, R.Larsen	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)
	Magnetic configuration and mechanisms of solar flares and CMEs	a) relationship between magnetic configurations and occurrences of flares and CMEs; b) magnetic instability buildup and development, and its role for occurrences of flares and CMEs; c) relationship between flares and CMEs.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) induction local correlation tracking: plasma flows on the photosphere; 3) MHD simulations: data assimilation against various flare/CME models; 4) PFSS, HCCSSS models: magnetic fields in the corona and heliosphere.	1) full disk vector magnetograms with 10 minute cadence and 6 hours interval; 2) full disk line-of-sight magnetograms with 1-minute cadence and 6-hour interval; 3) EUV images: temporal and spatial resolutions are of highest priority. Basic requirements are 2 minute cadence and 1-hour interval; 4) coronagraph images with a cadence better than 10 minutes and an interval longer than 1 hour. Data sets: MAG-5, MAG-4, MAG2	1) Y.Liu, T.Hoeksema, R.Larsen	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)

	Emergence of magnetic flux and solar transient events	a) whole process of emerging magnetic flux within active regions and within quiet regions; b) magnetic configurations of emerging magnetic fields, and their links/interactions with pre-existed magnetic fields; c) emerging magnetic flux and solar flares; d) emerging magnetic flux and eruptions of solar filaments; e) emerging magnetic flux and coronal mass ejections (CMEs). f) subphotospheric structures and dynamics associated with emerging magnetic flux	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) induction local correlation tracking: plasma flows on the photosphere; 3) MHD simulations: data assimilation against various flare/CME models; 4) PFSS, HCCSSS models: magnetic fields in the corona and heliosphere. 5) high-resolution time-distance and holographic methods	1) full disk vector magnetograms with 10 min cadence and 10 hour interval; 2) full disk line-of-sight magentograms with 1-min cadence and 10 hour interval; 3) EUV images: temporal and spatial resolutions are of highest priority. Basic requirements are 2 min cadence and 10 hour interval; 4) coronagraph images with a cadence better than 10 min and an interval longer than 1 hour. 5) high-resolution 24-hour Dopplergams Data set: MAG-3, HS-5	1) Y.Liu, T. Hoeksema, X.Zhao, A.Kosovichev, T.L. Duvall, jr, J. Zhao	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)
	Evolution of small-scale structures and magnetic carpets	a) topology structure of magnetic carpets; b) emerging, evolution and cancellation of small-scale magnetic elements, and the role for coronal heating and transformation of the large-scale fields.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures.	1) full disk vector magnetograms with 24 hour cadence and 120 hour interval; 2) full disk line-of-sight magentograms with 1-minute cadence and 120-hour interval; 3) EUV images: temporal and spatial resolutions are of highest priority. Basic requirements are 1 minute cadence and 120 hour interval. Data set: MAG-1, MAG-6	1)Y.Liu, T. Hoeksema	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)

Links between the internal processes and dynamics of the corona and heliosphere	Complexity and energetics of the solar corona	a) magnetic energy buildup and development in solar corona; b) origin and development of magnetic helicity in solar corona; c) topology structures of magnetic fields in both small-scale and large-scale, and their links and evolutions in the corona.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) induction local correlation tracking: plasma flows on the photosphere; 3) PFSS, HCCSSS models: magnetic fields in the corona and heliosphere; 4) MHD simulations: data assimilation against various mechanisms for energy storage and instability development.	1) full disk vector magnetograms with 10-minute cadence and 10-day interval; 2) full disk line-of-sight magentograms with 10-minute cadence and 10-day interval; 3) EUV images: 10-minute cadence and 10-day interval; 4) coronagraph images with a cadence better than 10-minute and an interval longer than 10-day. Data set: MAG-7	1) T.Hoeksema, X.Zhao, Y.Liu	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)
	Large-scale coronal field estimates	a) configurations of large-scale closed magnetic fields, and their relations with phases of solar cycle and CMEs; b) interchange of closed fields and open fields, and their relations with CMEs.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) PFSS, HCCSSS models: magnetic fields in the corona and heliosphere. 3) MHD simulations: explore relationship between magnetic configuration and CMEs.	1) full disk vector magnetograms with 10-minute cadence and 2-day interval; 2) full disk line-of-sight magnetograms with 10-minute cadence and 2-day interval; 3) EUV images: 1-hour cadence and 2-day interval; 4) coronagraph images with a cadence better than 1-hour and an interval longer than 2-day. Data set: MAG-8	1)X.Zhao, T.Hoeksema, Y.Liu, K.Hayashi 2) J.Linker, Z.Mikic	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)+ super-computer resources
	Coronal magnetic structure and solar wind	a) correlation between solar wind speed and magnetic flux expansion factor; b) how magnetic fields in active regions connect with interplanetary magnetic field lines, and what the properties of solar wind originated from solar active regions are; c) how interactions of streams produce co-rotating interaction regions.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) PFSS, HCCSSS models and MHD simulations: magnetic fields in the corona and heliosphere. 3) MHD simulations: how interactions of streams produce co-rotating interaction regions.	1) full disk vector magnetograms: one magnetogram per day for at least one month; 2) full disk line-of-sight magnetograms: one magnetogram per day or more; 3) EUV images: one image per day for one month or more; 4) in-situ observation of solar wind. Data set: MAG-8	1)T.Hoeksema, Y.Liu, X.Zhao, K.Hayashi	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)+ super-computer resources

Precursors of solar disturbances for space weather forecast	Far-side imaging and active index	a)detection of active regions on the far-side of the Sun in near-real time b) tracking developing active regions and forecast of their appearance on the Earth side	1) holographic imaging of the far-side	1) low-resolution full-disk continuous Dopplergrams 2)) full disk line-of-sight magnetograms: one magnetogram per day or more; Data sets: HS-7, MAG-8	1) D.Braun, C.Lindsey, P.H.Scherrer	1) support for CoRA
	Predicting emergence of active regions by helioseismic imaging	a) detection of emerging flux before it appears on the surface b) search for subphotospheric flow patterns associated with emerging magnetic flux	1) time-distance deep-focusing 2-hour sound-speed and flow maps 2) holographic images 3) line-of-sight magnetograms and NFFF reconstruction	1) full-disk continuous Doplergrams 2) full-disk 10-min cadence vector magnetograms Data sets: HS-5, MAG-1	1)A.G.Kosovichev, T.L.Duvall, Jr, J.Zhao	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE)
	Determination of magnetic cloud Bs events	a) relationship between magnetic helicity, structure and complex of solar source regions and the corresponding magnetic cloud Bs events; b) magnetic links between solar sources, solar eruptive events, and the re-lated magnetic cloud Bs events; c) propagation of disturbance with interaction with ambient solar wind, and its relation with Bs events.	1) iteration techniques and MHD evolution techniques: coronal magnetic fields and their topology structures; 2) induction local correlation tracking: plasma flows on the photosphere; 3) PFSS, HCCSSS models: magnetic fields in the corona and heliosphere. 4) MHD simulations: propagation of disturbance and its interaction with ambient solar wind.	1) full disk vector magnetograms with 10 minute cadence and 6 hours interval; 2) full disk line-of-sight magnetograms with 5-minute cadence and 6-hour interval; 3) EUV images: temporal and spatial resolutions are of highest priority. Basic requirements are 2 minute cadence and 1-hour interval; 4) coronagraph images with a cadence better than 10 minutes and an interval longer than 1 hour. Data set: MAG-5, MAG-7	1)Z.Zhao,Y.Liu, T.Hoeksema, K.Hayashi 2)J.Linker, Z.Mikic	LWS, HMI + additional support for data analysis, modeling and data assimilation tasks (1 FTE) + supercomputer resources

2.2.1 Objective 1. Convection-zone dynamics and the solar dynamo

Fluid motions inside the Sun generate the solar magnetic field. Complex interactions between turbulent convection, rotation, large-scale flows and magnetic field produce regular patterns of solar activity changing quasi-periodically with the solar cycle. How are variations in the solar cycle related to the internal flows and surface magnetic field? How is the differential rotation produced? What is the structure of the meridional flow and how does it vary? What role do the torsional oscillation pattern and the variations of the rotation rate in the tachocline play in the solar dynamo?

These issues are usually studied only in zonal averages by global helioseismology but the Sun is longitudinally structured. Local helioseismology has revealed the presence of large-scale horizontal flows within the near-surface layers of the solar convection zone. These flows possess intricate patterns that change from one day to the next, accompanied by more gradually evolving patterns such as banded zonal flows and meridional circulation cells. These flow structures have been described as Solar Subsurface Weather (SSW). Synoptic maps of these weather-like flow structures suggest that solar magnetism strongly modulates flow speeds and directions. Active regions tend to emerge in the stronger shear latitudes. The connections between SSW and active region development are presently unknown.

Main tasks:

1A.Structure and dynamics of the tachocline

1B.Variations in differential rotation

1C.Evolution of meridional circulation

1D.Dynamics in the near-surface shear layer

2.2.1.A Task 1A. Structure and dynamics of the tachocline

Major goals and significance

Direct observation of the deep roots of the solar activity in the tachocline located at the base of the solar convection zone, at 0.7 R, is of primary importance for understanding the long-term variability of the Sun. Recent results from MDI and GONG have revealed intriguing 1.3-year quasi-periodic variations of the rotation rate in the tachocline, which may be a key to understanding the solar dynamo. An important task of HMI is to confirm these findings and determine the relationship between the dynamics of the tachocline and magnetic activity. The major specific tasks are to determine:

a) The shape and thickness of the tachocline zone and its variations with solar cycle;

b) The latitudinal dependence of the evolving zonal flows at the base of the convection zone;

c) Longitudinal variations of the structure and flows at the base of the convection zone;

d) The relationship between the tachocline dynamics and magnetic activity.

These studies will provide information about the main processes of the Sun's magnetic activity cycle, and important constraints for theories of the solar dynamo.

Technical approach and methodology

Three primary methods of data analysis will be employed for this task:

1) Global helioseismology will provide normal mode frequency and frequency splitting measurements and inversions to infer the latitudinal and depth rotation rate and sound-speed and density structure of the tachocline and their variations with the solar cycle;

2) Time-distance helioseismology based on measurements and inversions of acoustic travel time will provide the longitudinal maps of the sound-speed variations and horizontal flows in areas of approximately 30x30 degrees, tracked for about 6 days;

3) Acoustic holography will attempt to detect local variations of the reflection properties of the tachocline, which are caused by concentrations of magnetic field, thermal perturbations and flows.

Science data requirements

Measurements in the deep solar interior require long time series. The global helioseismology results will be based on 72-day time series of Dopplergrams. It is important to have a good sample of these during a solar cycle to infer the solar cycle variations.

Single measurements by time-distance helioseismology and acoustic holography will use relatively short time series, 8-24 hour long. However, these measurements must be repeated over the period of several rotations to accumulate a good signal-to-noise ratio, sufficient for a data inversion procedure, which will be used to extract the properties of the tachocline from the travel time and phase variations. It is necessary to obtain good samples over at least a half of the solar cycle.

The helioseismic data must be accompanied by the corresponding measurements of the photospheric magnetic field in order to estimate the contribution of the near-surface inhomogeneities.

Science team roles and responsibilities

A significant experience in the global helioseismology data analysis methods and inversion procedure has been gained during the SOHO/MDI and GONG investigation. Basic software has been developed. However, it is required to significantly improve the precision of frequency splitting estimates for the p-modes that sample the tachocline region. Co-Investigators Rachel Howe and Jesper Schou are responsible for setting up the data analysis and inversion procedures for the global helioseismology part.

Both time-distance and holography parts require a substantial new development for both data analysis techniques and inversion procedures. So far, no robust measurements have been achieved by these methods in the tachocline region. Tom Duvall and Douglas Braun will lead these efforts. Alexander Kosovichev is responsible for the inversion procedure.

Required resources

Most of these investigations will be supported by using the HMI resources. A portion of the methodological time-distance research is currently supported by from a LWS theory and modeling grant. However, additional external support is necessary, in particular, for the holography studies. The required support includes some computer resources and salary for the Co-Investigator and a postdoctoral research associate.

2.2.1.B Task 1B. Variations in differential rotation.

Major goals and significance

Differential rotation is a crucial component of the solar cycle and is believed to generate the global scale toroidal magnetic field expressed in active regions. HMI will use global and local helioseismic techniques to measure the solar differential rotation, investigate relations between variations of rotation and magnetic fields, longitudinal structure of zonal flows ('torsional oscillations'), relations between the torsional pattern and active regions, measure the subsurface shear and its variations with solar activity, and the origin of the 'extended' solar cycle. The major goals of this investigation are to determine:

a) Differential rotation in the polar regions, short- and long-term variations of the rotation rate, and their relations to the polar magnetic field and the 'extended solar cycle' phenomenon;

b) The origin of the 'torsional oscillations', and their role in the solar cycle;

c) The driving mechanism of the differential rotation and related properties of solar turbulent convection.

Technical approach and methodology

For solving these problems it is essential to combine the results of the traditional inversions of rotational frequency splitting with inferences of local helioseismology and numerical models. More specifically, the technical approach is based on the following three methods:

1) Inversion of normal mode frequency splitting; this dataset will include high-degree modes and also more accurate measurements of tesseral modes of low angular order m, which probe the near-polar regions;

2) Investigation of patterns of differential rotation and torsional oscillations using synoptic maps of horizontal flows and sound-speed variations inferred by local helioseismology;

3) Inverse modeling and data assimilation based three-dimensional numerical simulations of turbulent solar convection; these will include nudging, adaptive Kalman-type filtering and other techniques to obtain information about properties of solar turbulence and thermal and magnetic effects that lead to the observed differential rotation law and torsional oscillations.

Science data requirements

The primary data set for the global helioseismology inversions is 72-day time series of full-disk Dopplergrams. Because of the better coverage of the Sun's polar regions the HMI will provide more accurate estimates of frequencies and frequency splitting of low-m modes, and thus will extend the zone of helioseismic inferences for the differential rotation and asphericity closer to the Sun's poles. Tracking the changes with the solar cycle in the near polar regions is extremely important for studying the mechanisms of the polar magnetic field reversals and the solar dynamo. Therefore, these measurements should continue for at least a half of the solar cycle.

The synoptic maps of subsurface flows and sound-speed structures will be made by two different techniques: time-distance helioseismology and ring-diagram analysis. The synoptic map methodology that is currently being developed for analysis of MDI full-disk Dopplergrams will be adopted for HMI. The time-distance procedure uses 512-min series of full-disk MDI Dopplergrams covering a central meridian zone 30^{o} wide and from -54^{o} to $+54^{o}$ in latitude. The horizontal resolution is 0.24^{o}; the vertical resolution varies from 1.5 to 3 Mm in the 0-20 Mm depth range. The HMI will allow extending the latitudinal coverage and improving the spatial resolution. The precise characteristics of the HMI subphotospheric synoptic maps will be determined when the HMI become available. The ring-diagram synoptic maps are obtained by measuring local frequency shifts in 15x15-degree areas on 7.5-degree grid, using 1-day time series. The depth resolution is similar to the time-distance technique. These two approaches are based on different properties of solar oscillations and, thus, provide independent estimates for solar rotation. Typically, the correlation coefficient between the time-distance and ring-diagram maps is 0.7-0.8.

Data assimilation and inverse modeling is a new approach for high-level data analysis. It employs numerical models for inferring physical properties of the solar dynamics, such as turbulent transport coefficients and Reynolds stress, from helioseismic inversion results. One of the methods which is being investigated is nudging, a method of dynamical relaxation. In nudging, the numerical models of the differential rotation are gently adjusted towards to the observations by adding a forcing function, in such a way that the difference between the observed and numerical results is minimized. This will allow us to track the corresponding changes in the model and made conclusions about the physical processes. This approach requires the inversion results for differential rotation and meridional circulation and 3D numerical simulations of solar convection in spherical geometry.

Science team roles and responsibilities

Co-Investigators, Rachel Howe and Jesper Schou, have taken the responsibility for the global helioseismology results. Tom Duvall leads the efforts for obtaining the synoptic flow and sound-speed maps by the time-distance technique. Juri Toomre, Richard Bogart, and Frank Hill coordinate the development of the ring-diagram method and analysis. Nagi Mansour have taken the lead in the data assimilation task.

Required resources

The production of the synoptic flow and sound-speed maps is a part of the HMI data processing, as well as the global mode analysis. Additional resources are required for the science analysis of these data, studying correlations with magnetic field and irradiance measurements and models, and numerical modeling and data assimilation (at least, 2 postdoctoral associates for these tasks). Also, an external support is required for the production ring-diagram synoptic maps and their analysis (1 research associate).

2.2.1.C Task 1C. Evolution of meridional circulation.

Major goals and significance

Precise knowledge of the meridional circulation is crucial for understanding the long-term variability of the Sun. Helioseismology has found evidence for poleward flow variation with the solar cycle. To understand the global dynamics we must follow the evolution of the flow. HMI will generate continuous data for detailed, 3-D maps of the evolving patterns of meridional circulation providing information about how flows transport and interact with magnetic fields during the solar cycle.

The key goals are to determine:

a) The latitudinal and depth dependences of the mean meridional flow;

b) The depth and speed of the reverse flow;

c) The existence of multiple meridional circulation cells;

d) The effects of the activity belts and active regions on the latitudinal structure and speed of meridional flows;

e) The longitudinal dependence of the meridional flows, and their relation with active longitudes.

Technical approach and methodology

The main tools for the investigation of meridional circulation are:

1) Local helioseismology based on the ring-diagram analysis and the time-distance technique; the time-distance results will be obtained by using two different approaches:
   a. Averaging the North-South component of velocity of the synoptic flow maps;
   b. Directly measuring averaged travel times of acoustic waves propagating in the North-South direction;
2) Correlation tracking of magnetic structures will provide a very important complementary information about the magnetic flux transport in the photosphere, and potential structure and strength of meridional flows in deeper layers;
3) Data modeling and assimilation by using 3D numerical models; these models typically show multiple cells, and the challenge is to match the observed flow, and determine the corresponding properties of solar turbulence (transport coefficients, Reynolds stress etc).

Science data requirements

The local helioseismology require 24-hour continuous series of Dopplergrams during at least 6 months each year (e.g. every other month). MDI results have demonstrated that 2-3 months per is insufficient for following the evolution of the meridional flows.

Science team roles and responsibilities

The local helioseismology ring-diagram effort is led by Juri Toomre and Frank Hill. The members of their teams are Deborah Haber, Brad Hindman, Rick Bogart, Rachel Howe, and Rudi Komm. The time-distance measurements are coordinated by Tom Duvall; the data inversions are carried out by Alexander Kosovichev and their colleagues. The magnetic field tracking task is not yet assigned. A similar study has been done by Nadege Meuner using the MDI data.

Required resources

The ring-diagram and magnetic field tasks will require an external support.

2.2.1.D Task 1D. Dynamics in the near-surface shear layer.

Major goals and significance

Helioseismology has revealed that the most significant changes with the solar cycle occur in the near-surface shear layer. However, the physics of these variations and their role in the irradiance variations are still unknown. HMI will characterize the properties of the near-surface shear layer, assay the interaction between surface magnetism and evolving flow patterns, and trace the modifications in the structure and dynamics as the solar cycle advances. It will assess the statistical properties of convective turbulence over the solar cycle, including the kinetic helicity and its relation the magnetic helicity – two most intrinsic characteristics of the dynamo action. The physics of the near surface turbulent layer is very rich. Here we identify only some initial goals of this investigation task, which are to determine:

a) Mean stratification and thermodynamic properties, testing the equation of state of the solar plasma;

b) Structure and dynamics of supergranulation, the depth of the reverse flow, mass and energy balance, the interaction with the rotational shear flow;

c) Variations of the subsurface shear flow with latitude and time;

d) Distribution of kinetic helicity, and its relation to large-scale magnetic patterns of the photosphere;

e) Excitation and damping mechanism of solar p- and f-modes; interaction between waves and turbulence;

f) Understanding of convective energy transport: most solar energy is transported to the solar surface by convection. Properties of the turbulent convection and its efficiency of transporting the energy flux may vary with both time and location. Therefore, it is extremely important to study the energetics of solar convection, and to establish the characteristics that affect the energy transport. Links between convection and the cycle can be manifested in the internal variations in wave speed, in the distribution of surface brightness, and in the shape of the solar limb. HMI will monitor these properties for an extended period of time, thus providing new insight in how the energy flows inside the Sun and affects solar irradiance.

Comprehensive multi-scale helioseismology and vector magnetic field data combined with the AIA observations of the solar corona will offer an unprecedented opportunity to solve the problem of the origin of solar activity, which puzzled people for almost four centuries since Galileo's discovery of sunspots, and is central to the LWS program.

Technical approach and methodology

The near surface shear layer is accessible by all helioseismology techniques, both global and local, and this allows us to cross-check the measurements, and obtain robust inferences of various physical properties of this layer. In particular, this methodology includes

1) Deriving latitudinal and depth dependencies of the rotation rate and sound-speed variations by inversion of global modes frequencies and frequency splitting;
2) Obtaining synoptic flow maps of various resolution by the local ring-diagram and time-distance methods, and then averaging these maps over longitude provides an independent estimate of the rotation rate and global latitudinal sound speed variations;
3) Using the surface gravity waves (f-modes) for both global and global diagnostics of subphotospheric and photospheric motions;
4) Studying correlations between subphotospheric flow patterns and characteristics of magnetic activity such as magnetic and kinetic helicity;
5) Comparing the observed properties of supergranulation and larger scale flows with results of numerical simulations.

Science data requirements

The global helioseismology investigations will employ the measurements of frequencies and frequency splitting for high-degree (l=200 – 2000) modes. The technique for these is being developed by Ed Rhodes and Johann Reiter. The current application this technique to the MDI data shows that it is extremely important to take into account the image distortions (these should be known to a high precision), as well as the mode interaction due large-scale inhomogeneities, like the differential rotation.

The local helioseismology require 24-hour continuous series of Dopplergrams during at least 6 months each year (e.g. every other month). MDI results have demonstrated that 2-3 months per is insufficient for following the evolution of the shear flows. The supergranulation studies by the time-distance technique require continuous 10-day chunks of Dopplergrams for tracking the evolution of supergranules as they move across the solar disk.

Science team roles and responsibilities

The local helioseismology ring-diagram effort is led by Juri Toomre and Frank Hill. The members of their teams are Deborah Haber, Brad Hindman, Rick Bogart, Rachel Howe, and Rudi Komm. The time-distance measurements are coordinated by Tom Duvall; the data inversions are carried out by Alexander Kosovichev and their colleagues.

Required resources

A full support is required for Johann Reiter and partial for Ed Rhodes to do high-l helioseismology analysis. Also, partial support is necessary for the members of the local helioseismology teams mentioned above. Additional funds are required to support 2 postdocs for developing data analysis and inversions, and for numerical simulations and analysis of mode excitation and damping, interaction with turbulent convection, the energy flow in the upper convections zone and links to irradiance variations. Also, substantial supercomputer resources are required for this task, for both data analysis and modeling.

2.2.2 Objective 2. Origin and evolution of sunspots, active regions and complexes of activity

Observations show that magnetic flux on the Sun does not appear randomly. Once an active region emerges, there is a high probability that additional eruptions of flux will occur in the neighborhood, or even in the same region (activity nests, active longitudes). How is magnetic flux synthesized, concentrated, and transported to the solar surface where it emerges in the form of evolving active regions? To what extent are the appearances of active regions predictable? What roles do local flows play in active region evolution?

HMI will answer these questions by providing tracked sound-speed and flow maps for individual active regions and complexes under the visible surface of the Sun combined with surface magnetograms. Current thinking suggests that the flux emerging in active regions originates in the tachocline. Flux is somehow pulled from the depths in the form of loops that rise through the convection zone and emerge through the surface. Phenomenological flux transport models show that the photospheric distribution of flux requires no long-term connection to flux below the surface. Rather, field motions are described by the observed poleward flows, differential rotation, and surface diffusion acting on emerged flux of active regions. Does the active region magnetic flux really disconnect from the deeper flux ropes after emergence?

Main tasks:

2A.Formation and deep structure of magnetic complexes of activity

2B.Active region source and evolution

2C.Magnetic flux concentration in sunspots

2D.Sources and mechanisms of solar irradiance variations

2.2.2.A Task 2A. Formation and deep structure of magnetic complexes.

Major goals and significance

HMI will explore the nature of long-lived complexes of solar activity (‘active or preferred longitudes’), the principal sources of solar disturbances. The phenomenon of ‘active longitudes’ has been one of the main puzzles of solar activity for many decades. Active longitudes may continue from one cycle to the next, and may be related to variations of solar activity on the scale of 1-2 years and short-term ‘impulses’ of activity. It is quite possible that the origin of active longitudes is related to a stable very large-scale circulation pattern in the convection zone (so-called, giant cells). HMI will probe beneath these features to 0.7R, the bottom of the convection zone, to search for correlated flow or thermal structures. The initial goals of this investigation are to:

a) search for a relationship between large-scale deep flow patterns and magnetic flux emergence in active longitudes;

b) search for large-scale sound-speed variations beneath complexes of activity in the deep interior (`thermal shadow’);

c) investigate the relationship between formation of complexes of activity, magnetic flux emergence, meridional circulation and magnetic flux transport to high latitudes;

d) investigate irradiance variations associated with complexes of activity.

Technical approach and methodology

This investigation will be mostly based on synoptic maps of sound-speed variations, subsurface flows and photospheric magnetic field. The deep-focus synoptic flow maps will be obtained at least by two independent methods of local helioseismology: time-distance technique and ring-diagram analysis. Additional information will be obtained by acoustic holography. The flow synoptic maps will provide information about the effects of active complexes on meridional circulation and torsional oscillations. It is also important to look for `nests’ of solar activity in near-surface regions. Therefore, we plan on using near-surface flow maps of flows and sound-speed structures by tracking with solar rotation large areas occupied by complexes of activity. The irradiance effects can be studied by measuring changes in the continuum intensity in large fixed areas of the solar disk as the active complexes rotate. The helioseismology results will be compared with magnetic synoptic maps and tracked magnetograms. It is essential to compare the flux transport at the surface with the circulation patterns in the interior.

Science data requirements

Preferred longitudes may exist for many solar rotations and, perhaps, even for a whole solar cycle. Therefore, the key requirement of this investigation is in continuous long-term observations of the convection zone dynamics, photospheric magnetic field and intensity. This task requires continuous full-disk, 50 sec cadence Dopplergrams for 120 or more days per year. The minimum science requirements for full-disk magnetograms are two 90-day periods per year. The intensity full-disk data are required for the same periods. The required data sets should cover the whole solar cycle, or at least the period from the solar minimum to maximum. Active longitudes are particularly prominent during the decaying and raising phases of the solar cycle. Therefore, it is particularly important to carry out this investigation during these periods.

Science team roles and responsibilities

Drs T.L. Duvall and A.G. Kosovichev will lead the investigation team which includes Drs Junwei Zhao, J.T. Hoeksema, E.E. Benevolenskaya of Stanford University, who will carry out the investigation by the time-distance method and magnetogram synoptic analysis. The ring-diagram investigation will be carried out by Drs. J.Toomre, D.Haber, and B.Hindman of University of Colorado, R. Howe and R. Komm of NSO, and Drs R.Bogart and J.Schou of Stanford.

Required resources

Support from the HMI and LWS programs is required for the team members. For data analysis, assimilation and modeling it will be necessary to support a postdoctoral researcher who will focus on this task and will combine the efforts of these groups.

2.2.2.B Task 2B. Active region source and evolution.

By using acoustic tomography we can image magnetic flux emergence and the disconnection that may occur. Vector magnetograms give evidence whether flux leaves the surface predominantly as 'bubbles', or whether it is principally the outcome of local annihilation of fields of opposing polarity. With a combination of helioseismic probing and vector field measurements HMI will provide new insight into active region flux emergence and removal. Initial goals of this investigation are:

a) tracking the lifecycle of selected active regions (emergence, evolution, decay);
b) detection of emerging flux in the interior;
c) search for the relationship between large-scale flow patterns and stability of active regions;
d) search for signatures of disconnection of magnetic flux from deep interior structures;
e) determination of the depth of the circulation flow around active regions;
f) establishing how active regions affect the structure and speed of meridional flows;
g) understanding the role of magnetic reconnections in the corona for the evolution of active regions;
h) detection of submergence of magnetic flux.

Technical approach and methodology

This investigation will be based on local helioseismology methods, particularly, on the time-distance technique which is capable of providing relatively high spatial and temporal resolutions. The high temporal resolution is critical because our preliminary study from MDI data showed that the emerging magnetic flux propagates very quickly through the upper convection zone, with a characteristic speed of 1.3 km/s. Therefore, temporal resolution should be 2 hours or less. This will require developing a time-distance measurements procedure for data with low signal-to-noise ration. Most of this is of the solar origin. The MDI investigation showed that the instrumental noise level of 20 m/s in the 50-sec-cadence, 1”-resolution Doppler images is acceptable for these measurements. For detection emerging regions in the deep interior we will use longer time series of 8 hours or longer, which will allow detection of relatively weak perturbations. It is also important to study the relationship between the subsurface dynamics and photospheric and coronal magnetic field topologies of the developing active regions. Thus, the technical approach consists of the following elements:

1) local helioseismology of selected active regions with 8-hour resolution (deep and surface focusing schemes)
2) time-distance analysis of emerging active regions for 2-hour intervals
3) investigation of the relationship between the synoptic flow patterns and local flows around active regions
4) correlation analysis between the internal flows and sound-speed perturbations and photospheric field

5) investigation of magnetic connectivity of active regions in the corona and their evolution.

Science data requirements

This is a complex investigation which requires helioseismology and magnetic data from HMI and coronal images from AIA. The required data are:

1) 24-hour time continuous Dopplergram series, 9-day tracking
2) 12-day continuous Dopplergrams, 20 periods per year
3) full-disk magnetograms, twenty 12-day periods per year
4) coronal EUV images

Data sets:
HS-2, HS-5, MAG-3

Science team roles and responsibilities

The science team for this task will lead Drs T.L. Duvall, Jr, A..G.Kosovichev, and include J. Zhao, S.Couvidat, E.E.Benevolenskaya, Y.Liu,T.Hoeksema, J.Toomre, R. Bogart, F. Hill, R, Howe, R. Komm, C.Lindsey, D.C. Braun, A.C. Birch. Drs Duvall, Kosovichev, Zhao and Couvidat will be responsible for the time-distance data analysis and inversions. Drs Hill, Howe and Komm will provide lower resolution maps from dense-packed ring-diagram analysis, and Drs Lindsey, Braun and Birch will be responsible for data analysis by acoustic holography.

Required resources

This task will require support for the team member from the LWS and SDO programs. Also, funds for 1 FTE will be necessary to work on unified data analyses, modeling and data assimilation.

2.2.2.C Task 2C. Magnetic flux concentration in sunspots.

Formation of sunspots is one of the long-standing problems of solar physics. Recent observations from MDI have revealed complicated flow patterns beneath sunspots and indicated that the highly concentrated magnetic flux in spots is accompanied by converging mass flows in the upper 3-4 Mm beneath the surface. The evolution of these flows is not presently known. HMI observations will allow investigating relations between the flow dynamics and flux concentration in spots, the flows in the deeper layers, below 4 Mm, providing detailed maps of the subsurface flows combined with surface fields and brightness for 9 days during the passage of sunspots on the solar disk. The initial research plan is the following:

a) establish the relationship between the flow dynamics and flux concentration in sunspots
b) study the relation between the Evershed effect and deep flow pattern
c) determine the relative role of temperature and magnetic perturbations in the sound-speed images
d) investigate the relation between the internal vortex flows, magnetic twists of sunspots and coronal activity
e) study the magnetic connectivity between sunspots in active regions in the solar atmosphere
f) investigate the possibilities for predicting the lifetime of sunspots by observing the internal circulation.

Technical approach and methodology

This task requires relatively high spatial resolution of the plasma flows and structures in the interior. It is essential to have 1”-resolution Dopplergrams and magnetograms for this study. The standard 8-hour temporal resolution for time-distance maps should be sufficient in most cases. However, rapidly developing sunspot will require 2-hour resolution. This can be achieved in this case by reducing the depth resolution. However the time-distance measurement parameters can be chosen on the case-to-case basis. Realistic 3D MHD numerical simulations are essential for interpretation of the observational results, understanding the physics of the interaction between the plasma convective flows and magnetic fields.

The basic technical approach and methodology consist of:

1) local helioseismology of selected active regions with 8-hour resolution (deep and surface focusing schemes)
2) time-distance analysis of rapidly growing sunspots for 2-hour intervals
3) studying the relationship local flows around sunspots, magnetic field, and EUV loop structures
4) numerical modeling and data assimilation.

Science data requirements

This task requires the following HMI and IAI data:

1) 24-hour time continuous Dopplergram series, 9-day tracking Dopplergram, 12-day continuous Dopplergrams for approximately 20 periods per year
2) full-disk magnetograms for twenty 12-day periods per year
3) corresponding coronal EUV images

Data sets: HS-2, HS-5, MAG-3

Science team roles and responsibilities

The time-distance flows and sound-speed maps will be provided by Drs T.L. Duvall, Jr, A..G.Kosovichev, J. Zhao, and S.Couvidat. Drs J.Toomre, R. Bogart, F. Hill R.Howe, and R. Komm will work on the ring diagram analysis to investigate large-scale flow patterns. Drs C.Lindsey, and D.C. Braun will investigate sunspots by acoustic holography, Drs N. Mansour and A.Wray are responsible for numerical simulations and data assimilation.

Required resources

For successfully completing this task the science team will need support form the LWS and SDO/HMI projects, plus additional support for data analysis, modeling and data assimilation tasks (2 FTE) and supercomputer resources.

2.2.2.D Task 2D. Sources and mechanisms of solar irradiance variations.

Magnetic features - sunspots, active regions, and network - that alter the temperature and composition of the solar atmosphere are primary sources of solar irradiance variability. How exactly do these features cause the irradiance variations? HMI together with the other SDO instruments AIA and EIS will study physical processes that govern these variations and the relation between the interior processes, properties of magnetic field regions and irradiance variations, particularly, the UV and EUV components that have a direct and significant effect on Earth's atmosphere. Currently, total solar irradiance variations are modeled by using semi-empirical approaches, in which brightness of various magnetic elements is assumed to be a function of the magnetic field. However, the physical mechanisms for the irradiance change are not established. By using the high-resolution continuous data from HMI we plan to investigate how the photospheric and subphotospheric physical properties of magnetic features are related to irradiance variations. In particular, the initial science includes investigation of:

a) Relationship between magnetic flux and the total irradiance

b) Effects of magnetic features on UV spectral irradiance

c) Relationship between the subphotospheric dynamics and irradiance variations

Technical approach and methodology

The technical approach and methodology are based on testing and calibrating traditional semi-empirical models for solar irradiance, and on new local helioseismology data about subphotospheric structures and mass flows, which will help to understand the convective energy flow below the surface. We plan to extend the irradiance models by including the subsurface characteristics. Therefore, the basic approach consists of

1) semi-empirical models for solar irradiance using magnetograms
2) local helioseismology of selected magnetic regions with 8-hour resolution (deep and surface focusing schemes) and investigation of characteristics of subsurface flows, related to the convective energy flow.

Science data requirements

These studies require high-resolution continuum intensity images with the flat-field calibration 0.1% or better. The 50-sec cadence data will be averaged over 5 min, typically, once every hour. The required completeness is 80% over at least 3 years. The full-disk magnetograms are averaged similarly and cover the same period, as well as the EUV images from AIA.

Summary of the required observational types:

1) Full-disk continuum intensity images, 2” resolution, 0.1% flat field, 5-min averages every hour, 80% completeness, for 3-years from solar minimum to maximum
2) Full-disk magnetograms, 2” resolution, noise level 7G/5min, 5-min averages every hour, 80% completeness, for 3-years from solar minimum to maximum
3) 24-hour time continuous Dopplergram series, 2” resolution, 25m/s noise, 50 sec cadence, 85% completeness, for 3-years from solar minimum to maximum; tracked 12 days 1”-resolution Doppler data for selected magnetic and quiet Sun regions, 95% completeness.
4) coronal EUV images

Data sets:

HS-2, HS-5, MAG-2, IC-1

Science team roles and responsibilities

The effort on developing semi-empirical irradiance models based on HMI magnetograms and continuum intensity data will be led by S.Solanki and Y.Liu. A.G.Kosovichev, T.L. Duvall and P.H.Scherrer will investigate the relationship between irradiance variations and subsurface dynamics. LWS, HMI, plus additional support for data analysis, modeling and data assimilation tasks (1 FTE) are required for this multi-instrument study.

2.2.3 Objective 3. Sources and drivers of solar activity and disturbances

It is commonly believed that the principal driver of solar disturbances is stressed magnetic field. The stresses are released in the solar corona producing flares and coronal mass ejections (CME). The source of these stresses is believed to be in the solar interior. Flares usually occur in the areas where magnetic configuration is complicated, with strong shears, high gradients, long and curved neutral lines, etc. This implies that the trigger mechanisms of flares strongly depend on critical properties of magnetic field that lead eventually to MHD instabilities. But what kind of instability actually works, and under what conditions it is triggered are unknown. Beside some theoretical ideas and models, there is no knowledge of how magnetic field is stressed or twisted inside the Sun or just what the triggering process is.

Main tasks:

3A.Origin and dynamics of magnetic sheared structures and delta-type sunspots

3B. Magnetic configuration and mechanisms of solar flares

3C. Emergence of magnetic flux and solar transient events

3D. Evolution of small-scale structures and magnetic carpet

2.2.3.A Task 3A. Origin and dynamics of magnetic sheared structures and δ-type sunspots.

Recent observations from MDI discovered complicated patterns of shearing and twisting flows beneath rapidly evolving active regions. Understanding the evolution of these flows and their coupling to activity requires continuous high-resolution observations. Particularly interesting targets of this investigation are δ-type sunspots. These spots contain two umbra of opposite magnetic polarities within a common penumbra and are the source of the most powerful flares and CMEs. The δ-type sunspot regions are thought to emerge magnetic flux into the solar atmosphere in a highly twisted state. It is important to determine what processes beneath the surface lead to development of these spots and make them active producing flares and CME. Thus, the initial tasks include studying:

a) relationship between subphotospheric flows and formation of delta-type sunspots and sheared magnetic structures
b) emerging flux and magnetic helicity in delta-spots
c) relationship between the subphotospheric dynamics and activity

Technical approach and methodology

The basic technical approach consists of:

1) time-distance analysis of delta-type sunspots for 2-hour intervals
2) local correlation tracking of magnetic elements
3) non-linear force-free magnetic field reconstruction
4) studying relationship between local flows around sunspots, magnetic field, and EUV loop structures

Science data requirements

1) 24-hour time continuous Dopplergram series, 9-day tracking; 12-day continuous Dopplergrams,
2) continuum images for at least 5 sunspots
3) full-disk magnetograms
4) coronal EUV images

Data sets:
HS-8, MAG-4, IC-2

Science team roles and responsibilities

This study will be led by A.G.Kosovichev, T.L. Duvall, Jr., J. Zhao, (time-distance analysis) Y.Liu, T.Hoeksema, and R.Larsen (analysis of magnetograms and continuum images).

Required resources

This task requires support from LWS and HMI projects, and additional support for data analysis, modeling and data assimilation tasks (1 FTE) for joint analysis of the multi-instrument data.

2.2.3.B Task 3B. Magnetic configuration and mechanisms of solar flares and CME.

Major goals and significance

It is commonly believed that the principal driver of solar disturbances is stressed magnetic field. The stresses are released in the solar corona producing flares and coronal mass ejections (CMEs). Flares, and flare-associated CMEs, usually occur in areas where the magnetic configuration is complex, with strong shears, high gradients, long and curved neutral lines, etc. This implies that the trigger mechanisms of flares/CMEs are controlled by critical properties of magnetic fields that lead eventually to MHD instabilities. But what kinds of instability actually govern, and under what conditions they are triggered are unknown. To answer these questions, observations are required that can measure both small-scale and large-scale fields simultaneously, can demonstrate continuous changes of magnetic field and electric current before events with sufficient spatial resolution, can show changes of the field strength and topology before and after events, and can exhibit plasma motion at the solar surface. HMI will provide unique measurements of the vector magnetic field over the whole solar disk with reasonable accuracy and at high cadence. These measurements will be used to infer the field topology configuration in both local scale and global scale, and to derive plasma motion and electric current in active regions. These are essential for understanding solar transient process. The major goals of this investigation are to determine:

a. relationship between magnetic configurations and occurrences of flares and CMEs;
b. magnetic instability buildup and development, and its role for occurrences of flares and CMEs;
c. relationship between flares and CMEs.

Technical approach and methodology

Four primary methods of data analysis will be taken to carry out this investigation:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate coronal magnetic fields in active regions and determine their topology structures;
b. Induction local correlation tracking (ILCT) is suggested to be used to infer the plasma flows on the photosphere;
c. The potential field source surface model (PFSS) and the horizontal current current sheet source surface model (HCCSSS) will be applied to reconstruct the magnetic fields in the corona and heliosphere;
d. MHD simulations are proposed to be employed to assimilate observations against various flares/CMEs models.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields and to infer plasma flows at the solar surface. Both are essential for MHD simulation experiments. The calculated magnetic fields help determine topology structures of the magnetic fields in the corona.

EUV observations are required to demonstrate behaviors of eruptions, and coronagraph measurements are needed to show development of the related CMEs. Generally, pre-flare phase can last 30 minutes to hours, impulsive phase lasts 2 minute to hours, and durations are from 10 minutes to hours. Thus the temporal and spatial resolutions of those observations are of high priority. Basically, EUV observation needs to have a cadence of 2 minutes and an interval longer than 1 hour. The coronagraph observation needs to have a cadence of 10 minutes and an interval longer than 1 hour.

Accuracy is of high priority for vector magnetic field measurements, especially for azimuth angle and the transverse magnetic field component. 2 arcseconds spatial resolution, 10 minutes cadence and 6 hours interval are required for this measurement. The requirements for line-of-sight magnetic field measurements are 1 arcsecond resolution, 1 minutes cadence and 6 hours interval.

It is necessary to accumulate good samples for this task. Dozens of major flares with/without CMEs associated and with/without eruptions of filaments associated are required. Both compact and two-ribbon flares are needed to be included in the samples.

Science team roles and responsibilities

Y.Liu, T.Hoeksema, X.Zhao, R.Larsen will provide magnetic field reconstructions in flaring regions, and coordinate the data analysis, interpretation and modeling.

Required resources

Support from LWS and HMI projects is necessary. Also, additional support is required for data analysis, modeling and data assimilation tasks (1 FTE).

2.2.3.C Task 3C. Emergence of magnetic flux and solar transient events.

Major goal and significance

Emergence of magnetic flux is closely related to solar transient events. Quick emergence of magnetic flux within active regions is found to be associated with flares. Emerging magnetic flux regions near filaments lead to eruption of filaments. CMEs are also found to accompany emerging flux regions. However, emergence of isolated active regions often does not cause any eruptive events. This implies that magnetic flux emerging into the atmosphere interacts with the pre-existing magnetic field leading to loss of magnetic field stability. HMI will provide vector magnetic field measurements over the whole solar disk with reasonable accuracy, sufficient resolution and high cadence. Such measurements enable researches carried out on revealing the whole processes of emergence of magnetic flux within active regions and quiet regions, mapping magnetic topology of emerging magnetic fields and seeking links and interactions of the newly emerging fields and pre-existing fields, and finally understanding relationship between solar transients and flux emerging. The major goals of this investigation are to determine:

a. the whole processes of emerging magnetic flux within active regions and within quiet regions;
b. magnetic configurations of emerging magnetic fields, and their links/interactions with pre-existing magnetic fields;
c. emerging magnetic flux and solar flares;
d. emerging magnetic flux and eruptions of solar filaments;
e. emerging magnetic flux and coronal mass ejections (CMEs).

Technical approach and methodology

For achieving these goals, it is necessary to trace the whole process of magnetic flux emerging, to couple the emergence of magnetic fields with pre-existing fields, and to investigate dynamic evolution of the whole system of magnetic field. To be more specific, the technical approach consists of four aspects:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;
b. Induction local correlation tracking (ILCT) is suggested to be used to infer the plasma flows on the photosphere;
c. The potential field source surface model (PFSS) and the horizontal current current sheet source surface model (HCCSSS) will be applied to reconstruct the magnetic fields in the corona and heliosphere;
d. MHD simulations are proposed to be employed to explore whole process of magnetic flux emerging and interaction between the newly-emerging flux and the pre-existing fields in both local scale and global scale.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields and to infer plasma flows at the solar surface. Both are essential for MHD simulation experiments. The calculated magnetic fields help determine topology structures of the magnetic fields in the corona.

EUV observations are required to demonstrate the process of magnetic flux emerging, the structures and behaviors of flares, and interactions of emerging flux and pre-existing fields. Coronagraph measurements are needed to reveal occurrences of CMEs, and to show CMEs' structures and behaviors.

Observationally, magnetic flux emerges quickly in the first 30 minutes, slows down in the coming 6 hours and stops completely after 10 hours. Thus observations are required to discern the quick emerging phase and to cover the whole process. Basically, the vector magnetic field measurements are required to have a cadence of 10 minutes, an interval of 10 hours, and a spatial resolution of 2 arcseconds. The line-of-sight magnetic fields are required to be measured with 1 minute cadence and 2 arcseconds resolution to detect emergence of magnetic flux. EUV observations are needed with a cadence better than 10 minutes, an interval as long as 10 hours and a resolution of 2 arcseconds. Coronagraph images are taken with a cadence better than 10 minutes and an interval longer than 1 hour.

It is necessary to accumulate good samples for this task. Dozens of cases for magnetic flux emerging within active regions and quiet regions are required. Both emergence of flux with and without eruptive events should be included in the samples.

Science team roles and responsibilities

Y.Liu, T. Hoeksema, X.Zhao will coordinate analysis and modeling of the magnetic field data for this task. A.Kosovichev, T.L. Duvall, Jr, J. Zhao will work on local helioseismology techniques and data analysis.

Required resources

The science team requires support from LWS and HMI projects. It is essential to have additional support for data analysis, modeling and data assimilation tasks (1 FTE).

2.2.3.D Task 3D. Evolution of small-scale structures and magnetic carpet.

Major goal and significance

The quiet Sun is covered with small regions of mixed polarity, termed ‘magnetic carpet’. These small-scale magnetic elements contribute to solar activity on short timescales. As these elements erupt through the photosphere they interact with each other and with larger magnetic structures such as those associated with active regions. They may provide triggers for eruptive events, and their constant interactions may be one of the sources of coronal heating. They may also contribute to irradiance variations in the form of enhanced network emission. HMI will make global scale observations of the small-scale magnetic element distribution, their interactions, and the resulting transformation of the large-scale field. The major goals of this investigation are to determine:

a. topology structure of magnetic carpets;
b. emerging, evolution and cancellation of small-scale magnetic elements, and the role for coronal heating and transformation of the large-scale fields.

Technical approach and methodology

The follow method of data analysis will be employed for this task:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;

Science data requirements

Vector magnetic fields are required to reconstruct coronal magnetic fields. High cadence line-of-sight magnetograms are required to demonstrate emerging, evolution and cancellation of magnetic elements, which are needed for coronal heating and transformation of large-scale field studies.

EUV observations are required to demonstrate magnetic connectivity and occurrences of bright points, which are suggested to be signatures of magnetic cancellation.

Lifetimes of magnetic networks and network elements are 100 hours and 50 hours, respectively. Observations are thus required to measure vector magnetic fields with 24-hour cadence and 120-hour interval, to measure line-of-sight magnetic fields with 1-minute cadence and 120-hour interval, and to take images in EUV wavelengths with 1-minute cadence and 120-hour interval.

Science team roles and responsibilities

This task will be coordinated by Y.Liu and J.T. Hoeksema

Required resources

The required resources include support from LWS and HMI including additional support for data analysis, modeling and data assimilation tasks (1 FTE).

2.2.4 Objective 4. Links between the internal processes and dynamics of the corona and heliosphere

The highly structured solar atmosphere is dominantly governed by magnetic field generated in the solar interior. Magnetic fields and the consequent coronal structures occur on many spatial and temporal scales. Intrinsic connectivity between multi-scale patterns increases coronal structure complexity leading to variable phenomena. For example, CMEs are believed to be related to the global-scale magnetic field, but many CMEs, especially fast CMEs, have been found to be associated with flares that are believed to be local phenomena. It is natural to link coronal structures and activity to internal processes and to link geoeffectiveness to solar coronal variability. However, it is a great challenge to provide a complete physical description to thoroughly explain the observed phenomena. Model-based reconstruction of 3-D magnetic structure is one way to calculate the field from observations. It has been shown that calculation from vector field data in active regions provides the best match to the observations. More realistic MHD coronal models based on HMI high-cadence vector-field synoptic data as boundary conditions are also anticipated to revolutionize our view of how the corona responds to evolving, non-potential active regions.

Main tasks:

4A.Complexity and energetics of the solar corona

4B.Large-scale coronal field estimates

4C.Coronal magnetic structure and solar wind

2.2.4.A Task 4A. Complexity and energetics of solar corona.

Major goal and significance

It is generally believed that solar flares and coronal mass ejections (CMEs) occur in solar corona. The corona has been shown complex and energetic. Origins of the complexity and energetics of solar corona are, however, still controversial. Two mechanisms, the photospheric shear motion and emerging magnetic flux, are suggested to be the origins, but which plays a dominant role and how the energy injection is related to eruptive events are unknown. HMI will provide vector magnetic field measurements over the whole solar disk with reasonable accuracy and high resolution and cadence. The measurements will be used to estimate partition of energy and helicity fluxes generated by these mechanisms, crossing through the photosphere and injecting into the corona. These measurements will also be used to investigate buildup and development of magnetic energy and instability. The major goals of this investigation are to determine:

a. magnetic energy buildup and development in solar corona;
b. origin and development of magnetic helicity in solar corona;
c. topology structures of magnetic fields in both small-scale and large-scale, and their links and evolutions in the corona.

Technical approach and methodology

The technical approach is based on the following four methods:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;
b. Induction local correlation tracking (ILCT) is suggested to be used to infer the plasma flows on the photosphere;
c. The potential field source surface model (PFSS) and the horizontal current current sheet source surface model (HCCSSS) will be applied to reconstruct the magnetic fields in the corona and heliosphere;
d. MHD simulations are proposed to be employed to explore various mechanisms for energy storage and instability development.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields and to infer plasma flows at the solar surface. Both are essential for MHD simulation experiments. The vector magnetic fields and plasma flow at the solar surface are required to estimate energy flux and helicity flux crossing through the surface. The calculated magnetic fields help determine topology structures of the magnetic fields in the corona.

EUV observations are required to demonstrate the process of magnetic flux emerging, the magnetic field structures and connectivity in various scales, and loops' interactions. Coronagraph measurements are needed to reveal occurrences of CMEs, and to show CMEs' structures and behaviors.

Observationally, reformation of streamer after CMEs, reformation of filaments after flares and reformation of sigmoids after flares are within a range from 10 minutes to days. Requirements for observations are thus 10-minute cadence, 10-hour interval and 2-arcsecond resolution for vector magnetic field, 1-minute cadence, 10-hour interval and 2-arcsecond resolution for light-of-sight magnetic field, 10-minute cadence, 10-hour interval and 2-arcsecond for EUV observation, and 10-minute cadence and 10-hour interval for inner coronal imaging.

Science team roles and responsibilities

J.T.Hoeksema, X.Zhao, Y.Liu will serve as coordinates for this task.

Required resources

The required resources include support for data analysis, modeling and data assimilation tasks (1 FTE)

2.2.4.B Task 4B. Large-scale coronal field estimates.

Major goals and significance

Configuration of large-scale magnetic fields in solar corona is an important component for determining sources of slow and fast solar winds and locating CMEs. Models computed from line-of-sight photospheric magnetic maps have been used to reproduce coronal forms that show multi-scale closed field structures as well as the source of open field which starts from coronal holes but spreads to fill interplanetary space. Modeled coronal field demonstrates two types of closed field regions, helmet streamers that form the heliospheric current sheet and another one that is sandwiched between the like-polarity open field regions. Recent results show evidence that most CMEs are associated with such helmet streamers and with newly opened flux. One important objective of HMI is to examine these results and to understand relationship of magnetic configuration of large-scale fields and CMEs, and evolution of magnetic configuration in solar cycle. The major tasks of this investigation are to determine:

a. configurations of large-scale magnetic fields, and their relations with CMEs and phases of solar cycle;
b. interchange of closed fields and open fields, and their relations with CMEs

Technical approach and methodology

Three primary methods of data analysis will be employed for this task:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;
b. The potential field source surface model (PFSS) and the horizontal current current sheet source surface model (HCCSSS) will be applied to reconstruct the magnetic fields in the corona and heliosphere;
c. MHD simulations are proposed to be employed to explore relationship between magnetic configuration and CMEs.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields and to infer plasma flows at the solar surface. Both are essential for MHD simulation experiments. High cadence line-of-sight magnetograms are required to create synoptic maps. These maps are used to extrapolate magnetic fields in the corona and heliosphere.

EUV observations are required to locate the sources of CMEs in solar surface and to demonstrate variation of coronal fields during events. Coronagraph measurements are needed to reveal occurrences of CMEs, and to show CMEs' structures and behaviors.

The data requirements for this investigation are 30-minute cadence, 10-hour interval and 2-arcsecond resolution for vector magnetic fields, 10-minute cadence, 10-hour interval and 2-arcsecond resolution for light-of-sight magnetic field, 10-minute cadence, 10-hour interval and 2-arcsecond for EUV observation, and 10-minute cadence and 10-hour interval for inner coronal imaging. The samples should cover one or half solar cycle.

Science team roles and responsibilities

Two groups will be involved in this important task

1) X.Zhao, T.Hoeksema, Y.Liu, K.Hayashi
2) J.Linker, Z.Mikic

The Stanford group will coordinate this effort.

Required resources

This task requires support for both groups including additional support for data analysis, modeling and data assimilation tasks (1-2 FTE) and supercomputer resources.

2.2.4.C Task 4C. Coronal magnetic structure and solar wind.

Major goals and significance

MHD simulation and current-free coronal field modeling based on magnetograms are two ways to study solar wind properties and their relations with coronal magnetic field structure. These methods have proven effective and promising, showing potential in applications of real-time space weather forecasting. It has been demonstrated that the modeling of solar wind can be improved significantly with increased cadence of the input magnetic data. By providing full disk vector field data at high cadence, HMI will enable these models to describe the distribution of the solar wind, coronal holes and open field regions, how magnetic fields in active regions connect with interplanetary magnetic field lines, and how interactions of streams produce co-rotating interaction regions. Specifically, the major tasks of this investigation are to determine:

a. correlation between solar wind speed and magnetic flux expansion factor;
b. how magnetic fields in active regions connect with interplanetary magnetic field lines, and what the properties of solar wind originated from solar active regions are;
c. how interactions of streams produce co-rotating interaction regions.

Technical approach and methodology

Three primary methods of data analysis will be employed for this task:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;
b. The potential field source surface model (PFSS), the horizontal current current sheet source surface model (HCCSSS), and MHD simulation experiments will be applied to reconstruct the magnetic fields in the corona and heliosphere;
c. MHD simulations are proposed to be employed to explore how interactions of streams produce co-rotating interaction regions.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields in active regions. Line-of-sight magnetograms are required to create synoptic maps. These maps are used to extrapolate magnetic fields in the corona and heliosphere.

EUV observations are required to reveal the boundaries of coronal holes. Coronagraph measurements are needed to demonstrate structures of streamers.

The data requirements for this investigation are 60-minute cadence and 10-arcsecond resolution for vector magnetic fields, 60-minute cadence and 10-arcsecond resolution for light-of-sight magnetic field, 60-minute cadence and 10-arcsecond for EUV observation, and 60-minute cadence for inner coronal imaging. The observation should cover at least one solar rotation for every 3 month in several years.

Science team roles and responsibilities

The research team for this task will be led by T.Hoeksema, Y.Liu, X.Zhao, and K.Hayashi.

Required resources

This task requires support for the science team from LWS and HMI projects, and includes additional support for data analysis, modeling and data assimilation tasks (1 FTE). Supercomputer resources are also required.

2.2.5 Objective 5. Precursors of solar disturbances for space-weather forecasts

Variations in the solar spectral irradiance and luminosity may have profound effects on life through their potential but poorly understood role in climate changes. The variation from cycle to cycle of the number, strength, and timing of the strongest eruptive events is essentially not presently predictable. We are far from answering simple questions like ‘will the next cycle be larger than the current one?’ Our understanding of the solar variations is fundamentally incomplete. To address the real-world questions we must solve this scientific problem. While developing correlative relations, detailed predictions must await a better understanding of the processes that govern the cycle. Meanwhile, there are several areas of investigation that can improve both our understanding of the cycle as a process. As we learn more about the fundamental processes through studies of internal motions, magnetic flux transport and evolution, relations between active regions, UV irradiance, and solar shape variations we will be vigilant for opportunities to develop prediction tools.

Main tasks:

5A.Far-side imaging and activity index

5B.Predicting emergence of active regions by helioseismic imaging

5C.Determination of magnetic cloud Bs events

2.2.5.A Task 5A. Far-side imaging and activity index.

A procedure for solar far-side imaging was developed using data from MDI, and has led to the routine mapping of the Sun's farside (http://soi.stanford.edu/data/farside/). Acoustic travel-time perturbations are correlated with strong magnetic fields, providing a view of active regions well before they become visible as they move onto the disk at the East limb. Synoptic images, which are now able to cover the entire far hemisphere of the Sun , will provide the ability to forecast the appearance of large active regions up to 2 weeks in advance and allow the detection of regions, which emerge just a few days before rotating into view. The initial science plan for this task is to develop robust approach for HMI data and carry out a routine daily procedure for:

1) detection of active regions on the far-side of the Sun in near-real time
2) tracking of developing active regions and forecast of their appearance on the Earth side

Technical approach and methodology

So far, the best results for the far-side imaging are obtained by the method of phase-sensitive acoustic holography. The far-side images represent daily maps of the phase difference between ingression and egression, and show locations of large active regions and sunspots on the far side. It will be important to develop a calibration procedure of these images and provide estimates of the magnetic flux. By this method, active regions once detected on the far side can tracked, and their appearance on the Earth side can be predicted.

Science data requirements

1) 2"-resolution full-disk continuous Dopplergrams, 85% coverage
2) full-disk line-of-sight magnetograms: one or more magnetograms per day;

Data sets: HS-7, MAG-8

Science team roles and responsibilities

D.Braun, C.Lindsey, P.H.Scherrer are responsible for this task.

Required resources

Support for CoRA is required from LWS or SDO funds.

2.2.5.B Task 5B. Predicting emergence of active regions by helioseismic imaging.

Rising magnetic flux tubes in the solar convection zone are likely to render significant Doppler signatures, which would provide forewarning of their impending emergence. Helioseismic images of the base of the convection zone will employ a similar range of p-modes as those used to construct images of the far side, and will have comparable spatial resolution. An important goal is to detect and monitor seismic signatures of persistent or recurring solar activity near the tachocline. This will serve as a basis for long-term forecasts of solar geomagnetic disturbances. New emerging active may be detected in the convection through the local variation of sound speed caused by changes in the convective energy flux and magnetic field, and also through specific large-scale flow patterns. The initial goals of this investigation are:

1) detection of emerging flux before it appears on the surface
2) search for subphotospheric flow patterns associated with emerging magnetic flux

Technical approach and methodology

Rapid emergence of active region will require deep-focus high-temporal resolution time-distance and holography imaging. The spatial resolution in these studies can be significantly reduced to obtain better signal-to-noise ratio. The local helioseismology results will be compared with the topological structure of emerging regions in an attempt to determine properties that may serve as indicators of the growth and evolution of the active regions. The key elements of this study are:

1) time-distance deep-focusing 2-hour sound-speed and flow maps
2) holographic images
3) line-of-sight magnetograms and NFFF reconstruction

Science data requirements

1) full-disk continuous Doplergrams
2) full-disk 10-min cadence vector magnetograms

Data sets: HS-5, MAG-1

Science team roles and responsibilities

A.G.Kosovichev, T.L.Duvall, Jr, J.Zhao will be responsible for this task, providing time-distance maps of emerging active regions. D.Braun and C.Lindsey will provide holographic images.

Required resources

Support from LWS and HMI programs is required, particularly, for the CoRA holography group. Additional support is necessary for data analysis, modeling and data assimilation tasks using all three types of analysis (1 FTE).

2.2.5.C Task 5C. Determination of magnetic cloud Bs events.

Major goals and significance

Long intervals of large southward interplanetary magnetic field, Bs events, and high solar wind speed are believed to be the primary cause of intense geomagnetic disturbances with the Bs component the more important quantity. It has been shown that orientation in ‘clouds’ remains basically unchanged while propagating from the solar surface to Earth’s orbit. This provides a plausible chain of related phenomena that should allow prediction to be made from solar observations of the geoeffectiveness of CMEs directed toward Earth. Estimates of embedded Bs will be improved significantly by incorporating frequently updated vector field maps into coronal field projections with the potential addition of coronal observations from AIA and STEREO. The major tasks of this investigation are to determine:

a. relationship between magnetic helicity, structure and complex of solar source regions and the corresponding magnetic cloud Bs events;
b. magnetic links between solar sources, solar eruptive events, and the related magnetic cloud Bs events;
c. propagation of disturbance with interaction with ambient solar wind, and its relation with Bs events.

Technical approach and methodology

Four primary methods of data analysis will be employed for this task:

a. Iteration techniques and MHD evolution techniques are proposed to be employed to calculate magnetic field structures and determine their topology;
b. Induction local correlation tracking (ILCT) is suggested to be used to infer the plasma flows on the photosphere;
c. The potential field source surface model (PFSS) and the horizontal current current sheet source surface model (HCCSSS) will be applied to reconstruct the magnetic fields in the corona and heliosphere;
d. MHD simulations are proposed to be employed to explore propagation of disturbance and its interaction with ambient solar wind.

Science data requirements

Vector magnetic fields are necessary data to reconstruct coronal magnetic fields and to infer plasma flows at the solar surface. Both are essential for MHD simulation experiments. High cadence line-of-sight magnetograms are required to create synoptic maps. These maps are used to extrapolate magnetic fields in the corona and heliosphere.

EUV observations are required to locate the sources of CMEs in solar surface and to demonstrate structures of coronal fields and related field reconstructions during events.

Coronagraph measurements are needed to reveal occurrences of CMEs, and to show CMEs' structures and behaviors.

The magnetic cloud Bs events are usually associated with Earth-directed CMEs. The data requirements for observations are thus similar to the one for flares and CMEs study. Specifically, the vector magnetic fields need to be measured with 10-minute cadence, 6-hour interval and 2-arcsecond resolution, the line-of-sight magnetic fields need to be measured with1-minute cadence, 6-hour interval and 2-arcsecond resolution, the EUV images need to be taken in 2-minute cadence, 1-hour interval and 2-arcsecond, and coronagraph observations for inner corona need to be made with 10-minute cadence and 1-hour interval.

It is necessary to accumulate good samples for this task. Dozen cases with good observational coverage showing CMEs' structures and developments and structures of magnetic clouds are needed. Cases of the CMEs associated with filament's eruption or with flare should be included.

Science team roles and responsibilities

Two groups will be involved in this important task

1) X.Zhao, T.Hoeksema, Y.Liu, K.Hayashi
2) J.Linker, Z.Mikic

The Stanford group will coordinate this effort.

Required resources

This task requires support for both groups including additional support for data analysis, modeling and data assimilation tasks (1 FTE) and supercomputer resources.

2.3 Secondary Science Objectives

The HMI Science Plan includes also several secondary objectives:

Low-Degree Helioseismology. The goal of this objective is to study the structure and dynamics of the solar core. To enable this study the disk-average noise of the HMI instrument should not exceed 0.1 m/s. These data will provide time series of Dopplergrams for accurate measurements of low-degree solar oscillations, and for search for g-modes using optimal mask methods.

Magnetic Field Variations in Solar Flares. MDI observations reveal two types of magnetic field variations associated with strong solar flares: permanent changes of the magnetic flux in the vicinity of the magnetic neutral line in the flare region, and impulsive variations which strongly correlate with hard X-ray flux. The variations of the first type are probably related to the magnetic energy release, and the variations of the second type are caused by the interaction of high-energy electrons and proton with the low atmosphere. The nature of the impulsive variations is unclear: they can be caused by a corruption of the spectral line profile by rapidly changing thermodynamic conditions and plasma motions, or by strong electric currents of the accelerated particles. HMI will allow us to investigate variations of the line profile during flares and determine the nature of the impulsive signal. Vector magnetograms will provide important information about the permanent changes of the magnetic field topology. MDI data indicate that most of the permanent changes occur in the horizontal component of magnetic field. For these studies the noise of the HMI magnetograms should not exceed 10G in 50 sec measurements, and for vector field the polarization accuracy should be better than 0.22% in 10 min.

Bright Ring Around Sunspots. Investigations of brightness variations around sunspots are important for understanding solar energy transport in the convection zone. Since the energy flux is inhibited in sunspots by strong magnetic field it is expected that the energy flows around the spot resulting in a bright ring. Such rings are observed in chromospheric lines, but there are no convincing observations in the photosphere. These brightness variations are below the MDI sensitivity. To enable these studies with HMI it is necessary to achive the noise level below 0.03% in continuum filtergrams. The flat field calibration should be better than 0.01%.

3 Scientific Approach

The investigation described above is a comprehensive broad based investigation into the sources and mechanisms of solar variability and its impact on the space environment. An investigation with this scope requires the dedicated efforts of a diverse team of researchers. The real constraint to the scientific return from SDO generally and HMI in particular is likely to be the limits to the support of people to pursue data analysis and theory development. The HMI investigation will attempt to optimize the scientific return be actively enabling Guest Investigators, as well as the HMI science team by providing convenient access to high level data products and workshops as appropriate.

HMI data and results will be crucial for the success of the whole SDO mission providing necessary key data for the coronal and irradiance instruments, in particular, magnetic filed measurements, energetic and helicity characteristics of active regions, flow maps associated with developing active processes. The goal is in cooperation with the coronal instruments, particularly, with AIA, SIE and WCI, to develop a system approach to develop knowledge and understanding the solar and heliospheric aspects of the Sun-Earth system that directly affect life and society.

Important cooperation will be developed with other space missions and ground-based observatories. In particular, HMI will take over from MDI to provide a missing key observation to support STEREO data interpretation. Because STEREO has no magnetographs it must rely on other observatories for monitoring the solar magnetic field conditions during its target CME event studies. The spatial resolution and vector capability of HMI will provide the basis for modeling the corona and solar wind underlying STEREO CMEs, as well as indications of the causes of these transients. HMI will also provide global context for Solar B vector measurements that are focused on specific active regions, and also information on coronal holes and solar wind stream structure used in the interpretation of L1 solar wind monitor data from spacecraft like ACE. In the area of helioseismology cooperation with the GONG+ project will play very important role for cross-checks of helioseismic inferences in the common range of spatial and temporal resolution.

4 Theoretical Support and Modeling

The maximum scientific benefit from HMI can be obtained only with a specific theoretical program which includes numerical simulations of wave excitation and propagation in magnetized plasma, magnetoconvection, local and global dynamo processes, magnetic flux emergence, magnetic structures and MHD processes in the solar corona. Theoretical models for inversion of helioseismic and magnetic data are also extremely important for HMI data analyses. The inversion algorithms needs to be sufficiently fast to provide the science data products which are required for studying precursors of solar disturbances, such as full-disk maps of subsurface flows, far-side images and vector magnetograms, in almost real time. As a part of this project we will operate a 3-D radiation MHD code that is being developed by HMI Co-Is at the NASA Ames Research Center. The member of our research team will actively participate in the coordinated SDO Guest Investigator and LWS Theory and Modeling Programs.

5 Scientific Operation Modes and Requirements

The scientific operation modes and data products can be divided into four main areas: global helioseismology, local-area helioseismology, line-of-sight and vector magnetography and continuum intensity studies. The principal data flows and products are summarized in Table C.2.2. These four primary scientific analyses cover all main HMI objectives, and have the following characteristics:

•*Global Helioseismology: Diagnostics of global changes inside the Sun.* The traditional normal-mode method will produce large-scale axisymmetrical distributions of sound speed, density, adiabatic exponent and flow velocities through the whole solar interior from the energy-generating core to the near-surface convective boundary layer. These diagnostics will be based on frequencies and frequency splitting of modes of angular degree up to 1000, obtained for several day intervals each month and up to l=300 for each 2-month interval. These will be used to produce a regular sequence of internal rotation and sound-speed inversions to allow observation of the tachocline and average near surface shear.

•*Local-Area Helioseismology: 3D imaging of the solar interior.* New methods of local-area helioseismology, time-distance technique, ring-diagram analysis and acoustic holography represent powerful tools for investigating physical processes inside the Sun. These methods on measuring local properties of acoustic and surface gravity waves, such as travel times, frequency and phase shifts. They will provide images of internal structures and flows on various spatial and temporal scales and depth resolution. The targeted high-level regular data products include:

- Full-disk velocity and sound-speed maps of the upper convection zone (covering the top 30 Mm) obtained every 8 hours with the time-distance methods on a Carrington grid;
- Synoptic maps of mass flows and sound-speed perturbations in the upper convection zone for each Carrington rotation with a 2-degree resolution, from averages of full disk time-distance maps;
- Synoptic maps of horizontal flows in upper convection zone for each Carrington rotation with a 5 degree resolution from ring-diagram analyses.
- Higher-resolution maps zoomed on particular active regions, sunspots and other targets, obtained with 4-8-hour resolution for up to 9 days continuously, from the time-distance method;
- Deep-focus maps covering the whole convection zone depth, 0-200 Mm, with 10-15 degree resolution;
- Far-side images of the sound-speed perturbations associated with large active regions every 24 hours.

In addition, to this standard set new approaches such waveform tomography of small-scale structures will be developed employed.

• *Magnetography. Complete coverage of magnetic processes in the photosphere.* The traditional line-of-sight component of the magnetic field is produced as a co-product with the Doppler velocity observations used for helioseismology. This observable has proven to be very useful in tracking magnetic field evolution at all time and size scales. Several products will be computed with various cadence and resolution for use as input to coronal field and solar wind models and correlative studies.

The vector magnetic field is one of the most important physical observables of the active solar atmosphere. HMI will produce several standard data series of vector fields. A 'magnetograph mode' analysis will be computed routinely and continuously to provide boundary conditions for large scale coronal modeling. HMI, with help of robust inversion technique, will also provide AR tracked and full-disk on-request vector magnetic field, filling factor and the thermodynamic parameters of the photospheric plasma within reasonable errors. These data will be used to quantitatively measure the free energy of magnetic field, magnetic stresses and helicity, providing important input to many prime science objectives and tasks of HMI and other SDO investigations.

- *Continuum Intensity: Identification of irradiance sources.* The observations of the intensity in the continuum near the HMI spectral line will give a very useful measure of spot, faculae area and other sources of irradiance. This will be important for studying the relationship between the MHD processes in the interior and lower atmosphere and irradiance variations. The continuum data will be also used for limb shape analysis, and for public information and education purposes.

- *Real Time Product*s: *Data for planning and prediction of space weather events.* Some of data products will be made available for space weather investigations and forecasts in real time. The immediately available products includes: calibrated magnetograms, Doppler velocity and continuum intensity images. On the regular basis (daily or more often) we will provide full-disk maps of sound speed distribution and mass flows in the upper convection zone, and far-side activity index maps.

5.1 Scientific Data Products

The scientific operation modes and data products can be divided into four main areas: global helioseismology, local-area helioseismology, line-of-sight and vector magnetography and continuum intensity studies. The principal data flows and products are summarized in Figure 1 and Tables 1-3. The instrument requirements are summarized in Table 4.

The following five primary scientific analyses cover all main HMI objectives, and have the following characteristics:

- *Global Helioseismology: Diagnostics of global changes inside the Sun.* The normal-mode method will be used to obtain large-scale axisymmetrical distributions of sound speed, density and flow velocities throughout the solar interior from the energy-generating core to the near-surface convective boundary layer. These diagnostics will be based on frequencies and frequency splitting of modes of angular degree (l) up to 1000, obtained for intervals of several days each month and up to l=300 for each 2-month interval. These will be used to produce a regular sequence of internal rotation and sound-speed inversions to allow observation of the tachocline and the near-surface shear layer.

- *Local Helioseismology: 3D imaging of the solar interior.* The time-distance technique, ring-diagram analysis and acoustic holography represent powerful tools for investigating physical processes inside the Sun. These methods are based on measuring local properties of acoustic and surface gravity waves, such as travel times, frequency and phase shifts. The targeted high-level regular data products include:

    - synoptic maps of mass flows and sound-speed perturbations in the upper convection zone for each Carrington rotation with a 2-degree resolution, from averages of full disk time-distance maps;
    - synoptic maps of horizontal flows in the upper convection zone for each Carrington rotation with a 5-degree resolution from ring-diagram analyses;
    - higher-resolution maps zoomed on particular active regions, sunspots and other targets, obtained with 4-8-hour resolution for up to 10-day transits;
    - deep-focus maps covering the whole convection zone depth, 0-200 Mm, with 10-15 degree resolution;
    - farside images of travel-time perturbations associated with large active regions every 12 hours.

These observations require uninterrupted series of Dopplergrams of lengths 8 to 24 hours with the following characteristics: 50-second (or higher) cadence, spatial sampling of 2 Mm for distances up to 75 degrees from the disk center, and the noise level better than 20 m/s.

- *Magnetography. Complete coverage of magnetic processes in the photosphere.* The traditional line-of-sight component of the magnetic flux is produced as a co-product with the Doppler velocity. Several products will be computed with various cadence (up to 10 minutes) and resolution for use as input to coronal field and solar wind models and correlative studies. To accurately model the global fields the zero point accuracy should be better than 0.1G.

•*The vector magnetic field.* This is one of the most important physical observables of the active solar atmosphere. HMI will produce several standard data series of vector fields. A simple 'magnetograph mode' analysis will be computed continuously in real time for large scale coronal modeling and other space weather applications. With help of inversion techniques[113], HMI will also provide tracked and full-disk vector magnetic field, filling factor, and thermodynamic parameters of photospheric plasma within reasonable errors. The data will be used to measure free energy, stresses and helicity of the magnetic field, providing important input to many prime science objectives and tasks of HMI and other SDO investigations. These polarimetric observations require a few minutes temporal cadence, a spatial sampling of 0.5", and a 0.3% polarization precision to yield 5% accuracy of the magnetic field strength, a few tens of degrees in inclination and azimuth in strong fields.

• *Continuum Intensity: Identification of irradiance sources.* The observations of the intensity in the continuum near the HMI spectral line will give a very useful measure of spot, faculae area and other sources of irradiance. This will be important for studying the relationship between the MHD processes in the interior and lower atmosphere and irradiance variations. The continuum data will be also used for limb shape analysis, and for public information and education purposes. These measurements require calibration of system pixel-pixel gain variations to a level 0.1%, as demonstrated with MDI.

Table 2 Relationship Between HMI Science Objectives and Data Products

Relationship between HMI science objectives (Proposal section C1) and data products (Proposal Foldout.1 Section L)		Internal rotation $\Omega(r,\Theta)$ $(0<r<R)$	Internal sound speed, $cs(r,\Theta)$ $(0<r<R)$	Full-disk velocity, $v(r,\Theta,\Phi)$, And sound speed, $cs(r,\Theta,\Phi)$, Maps (0-30Mm)	Carrington synoptic v and cs maps (0-30Mm)	High-resolution v and cs maps (0-30Mm)	Deep-focus v and cs maps (0-200Mm)	Far-side activity index	Line-of-Sight Magnetic field maps	Vector Magnetic Field maps	Coronal magnetic Field extrapolations	Coronal and Solar wind models	Brightness Images	EUV Images, i.e. AIA	Coronagraph Images	EUV Spectral Irradiance
Convection zone dynamics and solar dynamo	Structure and dynamics of the tachocline	HS-1	HS-1				HS-2		MAG-1							
	Variations in differential rotation	HS-1		HS-3	HS-3		HS-2		MAG-1							
	Evolution of meridional circulation			HS-3	HS-3	HS-3	HS-2		MAG-1							
	Dynamics in the near surface shear layer	HS-3		HS-3	HS-3	HS-3			MAG-1							
Origin and evolution of sunspots, active regions and complexes of activity	Formation and deep structure of magnetic complexes of activity				HS-4	HS-4		HS-2	MAG-1		MAG-2					
	Active region source and evolution			HS-5	HS-5	HS-5		HS-2	MAG-3							
	Magnetic flux concentration in sunspots			HS-5	HS-5	HS-5			MAG-3							
	Sources and mechanisms of solar irradiance variations			HS-6	HS-6		HS-6		MAG-1	MAG-1			IC-1	X		X
Sources and drivers of solar activity and disturbances	Origin and dynamics of magnetic sheared structures and δ-type sunspots					HS-8				MAG-4	MAG-4		IC-2			
	Magnetic configuration and mechanisms of solar flares								MAG-5	MAG-5	MAG-4	MAG-2		X	X	
	Emergence of magnetic flux and solar transient events.					HS-5			MAG-3	MAG-3	MAG-3			X		

Relationship between HMI science objectives (Proposal section C1) and data products (Proposal Foldout.1 Section L)		Internal rotation $\Omega(r,\Theta)$ ($0<r<R$)	Internal sound speed, $cs(r,\Theta)$ ($0<r<R$)	Full-disk velocity, $v(r,\Theta,\Phi)$, And sound speed, $cs(r,\Theta,\Phi)$, Maps (0-30Mm)	Carrington synoptic v and cs maps (0-30Mm)	High-resolution v and cs maps (0-30Mm)	Deep-focus v and cs maps (0-200Mm)	Far-side activity index	Line-of-Sight Magnetic field maps	Vector Magnetic Field maps	Coronal magnetic Field extrapolations	Coronal and Solar wind models	Brightness Images	EUV Images, i.e. AIA	Coronagraph Images	EUV Spectral Irradiance
	Evolution of small-scale structures and magnetic carpet					MAG-6			MAG-1	MAG-6				X		
Links between the internal processes and dynamics of the corona and heliosphere	Complexity and energetics of the solar corona								MAG-7	MAG-7	MAG-7	MAG-7	MAG-7	X	X	
	Large-scale coronal field estimates										MAG-8	MAG-8		X	X	
	Coronal magnetic structure and solar wind									MAG-8	MAG-8	MAG-8		X	X	
Precursors of solar disturbances for space-weather forecasts	Far-side imaging and activity index							HS-7	MAG-8	MAG-8					X	
	Predicting emergence of active regions by helioseismic imaging			HS-5	HS-5	HS-5			MAG-1	MAG-1				X		
	Determination of magnetic cloud Bs events								MAG-7	MAG-5	MAG-7	MAG-8			X	

5.2 HMI Science Data Measurements.

The data observing sequences that are used as input for analyses are described here as a number of observation types. The Observation Types that support the various science objectives are shown in the HMI Objectives-Data Table (Table 2). Observation Types are described below.

Table 3. Observation Types

Observation	**Observable, object**	**Instances or % of intervals**	**Observing interval**	**Completeness in interval**	**Span of observations**	**Res**	**Notes**
HS-1	V, fd	12	72-day	95%	3-years	2”	
HS-2	V, fd	80%	24-hour	85%	3-years	2”	
HS-3	V, fd	2	90-day	95%	Min-max		2 per year
HS-4	V, ARs	5	120-day	95%	Active Sun		
HS-5	V, ARs	100	12-day	95%	Any	1”	>10 “large”
HS-6	V, fd	60%	24-hour	95%	Min-max	2”	Max gap 30h
HS-7	V, fd	80%	10-hour	95%	Min-max	2”	Max gap 30h
HS-8	V, ARs	>5 delta-spots	10-day	95%	Any	1”	Need to sample several at all phases of life
MAG-1	B-5m, fd	80%	5-min/hour	80%	3-years	2”	Max gap 10h
MAG-2	B-5m, fd	10%	5-min/hour	80%	3-years	2”	Min 2/day
MAG-3	B, ARs	100	12-day	95%	Any	1”	>10 “large”
MAG-4	B, ARs	>5 delta-spots	10-day	95%	Any		
MAG-5	B, ARs	50 ARs with flares	2-day	95%	Any		>2 X-class
MAG-6	B, fd	Monthly	3-day		Min-max		
MAG-7	B,fd	50%	60-day	85% for HS	Min-max		
MAG-8	B or Bvec	3 per day 80% of time	20-min		Min-max		
IC-1	Ic,fd	80%	5-min/hour	80%	3-years	2”	Max gap 10h
IC-2	Ic,fd	>5 delta spots	10-day	95%	Min-max	1”	

Observation Type HS-1

Global HS synoptic uses typically 72-day intervals. Repeated intervals are needed to follow solar variations with changes in solar activity. Loss of a few intervals in a three year span would still yield important results to extend the SOHO/MDI results into the next cycle. If GONG continues into the SDO mission years these observations have a somewhat lower priority since higher-noise but still very useful data can be obtained with GONG. In the past seven years GONG has (in 36-day intervals) coverage in the range of 70 to 85% (of the minutes). MDI has typically 96-97% coverage except of course for the large gaps. For low-degree (less than l=120) modes we believe most of the noise difference results from coverage completeness. We believe that coverage less than ninety something percent results in noticeable noise, probably the limit is about 90. We believe that solar noise is such that the noise in the frequency fits with coverage between about 95% and 100% is indistinguishable. Thus 95% is a good place to be sure that we are limited by solar noise rather than noise from data gaps. Where there are gaps we have found that random times of random sizes is least damaging. Gap filling methods can recover most of the signal when the gap is less than 10% of the surrounding spans of more complete data.

Observation Type HS-1 Table Entry

Type	Observing Sequence Needed	Obse-rvables	Planned Span of Observa-tions	Planned Number of Observations (percent coverage)	Minimum Span of Observations	Minimum Number of Observations (percent coverage)	Minimum Image resolution	Notes
HS-1	OS-1	fd_V, fd_Ic	5-years	25 (100%)	3-years	12 (80%)	2”	Global structure and rotation

Observing Sequence Type OS-1 Table Entry

Observing Sequence Type	Nominal Interval	Completeness in interval	Max harmless gap	Optimum Gap distribution	Notes
OS-1	72d	95%	90s	random	

Observation Type HS-2

Global Scale Local Method Helioseismology. HS-2. This type of observation supports measurement of deep-in-the-Sun flows and possibly fields. The method uses time-distance techniques to probe the conditions in the vicinity of the tachocline and bottom of the convection zone. This is about 200Mm deep. The end-points of acoustic rays that turn at this depth are about 700Mm apart, i.e. about a solar radius. This means that only a narrow range of longitude or latitude from disk center can be probed. With end points about 60 degrees apart and limiting data to about 75 degrees from disk center (0.96R where projection factor is about 4) the distance from disk center at the turning point is at most about 45 degrees. A "point" could then be tracked for 90 degrees or about 6 days. Doppler noise near the limb may restrict the range to +-60 degrees (0.87R, factor of 2 in projection) giving a 60 degree or 4 day maximum observing sequence. Experiments have shown useful S/N for one day sequences .Due to the wavelength of waves at the tachocline (c. 70Mm) the maximum resolution achievable is about 10 degrees. Thus about 5 resolution elements are detectable for each day-long sequence and 36 elements covers a rotation. This means the minimum requirement is 8 one-day sequences per month with at most 4-day gaps.

Type	Observing Sequence Needed	Observables	Planned Span of Observations	Planned Number of Observations (percent coverage)	Minimum Span of Observations	Minimum Number of Observations (percent coverage)	Minimum Image resolution	Notes
HS-2	OS-2	fd_V	5-years	1800 (98%) allows 5 lost days/yr	3-years	300 with max gap of 4 days (25%)	2"	Tachocline structure from time-distance

Observing Sequence Type OS-2 Table Entry

Observing Sequence Type	Nominal Interval	Completeness in interval	Max harmless gap	Optimum Gap distribution	Notes
OS-2	24h	85%	90s	bunched	

Observation Type HS-3

Sub-Surface "Weather" – SSW. This type of observation supports both Time-Distance and Ring type analyses (as well as holographic techniques). The goal is to study the region from the surface to 30Mm in detail and watch global and AR scale flows as they evolve. Sequences of a day are tracked in data cubes of typically 15-degrees or 7.5 degrees (perhaps 5 degrees with HMI). The Sun's disk is tiled with overlapping tracked cubes and flow analysis is performed on each cube. MDI has shown changes on day time scales with larger scales persistent for rotations (or years in case of zonal flows a.k.a. torsional oscillations). MDI has only allowed one 2-rotation sequence per year. This is not sufficient to determine the persistence or nature of evolution of active region scale or even radius-scale flows. We believe a minimum of three contiguous rotations at least once each six months would yield important data on these flows. We should sample over the full rising part of the cycle – i.e. from min to max. The base plan is for continual mapping. One important component of large scale solar flows is the meridional or poleward flows. They have typical amplitudes of several m/s. We should be able to detect real variations down to c. 1 m/s. To avoid leakage of the 2 km/s solar rotation signal into the meridional signal we must know the roll orientation to better than 2 arc-min.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-3	OS-3	fd_V	5-years	20 (100%)	Min to max	6 – one 3-rotation sequence each 6 months	2"	Large scale subsurface "weather"

Observing Sequence Type OS-3 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-3	90d	95%	90s	random	

Observation Type HS-4

Active Longitude Studies. This observation type will provide data for the examination of the source of active zones or longitudes or complexes of activity. We know a good deal statistically about the clumpiness of activity but do not know of any internal cause for such clumping. This study will use techniques nearly identical to HS-3 except that longer contiguous spans are required. We believe we need at least 4-rotation spans of synoptic maps of sub-surface flows. Both Ring and Time-Distance analyses will be applied. Time-Distance prefers clumped gaps and Rings prefer random gaps.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-4	OS-4	fd_V	5-years	15 (100%)	3-years	5 four-rotation sequences (55%)	2”	Active Longitudes

Observing Sequence Type OS-4 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-4	120d	95%	90s	random	

Observation Type HS-5

Active Region Studies. This observation type produces data to allow study of flows, thermal, and field structure beneath active regions. Both Time-Distance and Holographic methods will be used. Since the details in the near surface layers are important the highest resolution data will be needed. The wavelength of acoustic waves near the surface is about 2Mm and this sets a natural resolution target. Active regions have lifetimes of weeks to months. If data is used to about 0.93 R then a 1Mm pixel subtends 0.5". This gives a 10-day span of coverage. 12-days coverage with 0.5" pixels corresponds to 2Mm pixels with data used out to 0.98R. We would hope to obtain clean data for 10-day spans with analyses extended to 12-day spans with allowances for lower resolution at the ends. This means we can observe 20-50% of the lifetime of many active regions with full coverage of many short lived small regions. With this coverage we should be able to determine the flow-evolution from prior to eruption to post-visibility for small, typical, and a few large regions. We estimate that a sample of 100 regions tracked for 12-days each will yield at least 10 large region segments and we consider this to be a minimum requirement for this study. The baseline plan calls for tracking all active regions with NOAA identification. 100 regions can be captured in about 2.5 years starting at minimum or in less than six months near a typical maximum of activity. Since Time-Distance methods will be used gaps should be clumped into as few sub-intervals as possible. Ring type analyses do not give enough resolution for these studies.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-5	OS-5	fd_V	5-years	100%	2.5-years starting at min or 1 year at max	100 regions	2"	Active Regions, Multiple regions concurrently

Observing Sequence Type OS-5 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-5	12d	95%	90s	clumped	

Observation Type HS-6

Irradiance Sources Studies. This observation type produces data to allow study of flows, thermal, and field structure associated with large-scale magnetic structures. Time-Distance methods will be used. The goal is to provide maps of the interior structures and flows over the whole disk at least once a day. The depth coverage is about 30 Mm for this maps; 2” resolution should be sufficient. This will allow us to cover most of the visible disk. The irradiance studies should cover at least 3 years, from solar minimum to maximum. This data may be also for ring-diagram analysis. However, the disk coverage will be limited.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-6	OS-6	fd_V	3-years	95%	3-years starting at min including 1 year at max	80%	2”	Full-disk maps of flows and sound-speed up to 30Mm

Observing Sequence Type OS-6 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-6	24d	95%	90s	random	Max gap 30h

Observation Type HS-7

Far-side Imaging. This observation type produces data to allow detection and tracking of active regions on the far side of the Sun. Holographic method will be used. 10-hour long time series of 2” resolution Dopplergram are required to produce one far-side image. The planned span of observation is for the whole mission lifetime, or at least for 3 years. These are of high interest for space weather research, and should be carried out continuously for the mission. The minimum period of 3 years from min to max will allow establishing the relationship between these images and the magnetic flux and enabling global modeling of the Sun’s magnetic properties.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-7	OS-7	fd_V	3-years	95%	3-years starting at min, including 1 year at max	80%	2”	Far-side images, one every day

Observing Sequence Type OS-7 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-7	10d	95%	90s	random	Max gap 30 hours

Observation Type HS-8

Delta-type Sunspot Studies. This observation type produces data to allow study of flows, thermal, and field structure associated with formation and evolution of delta-type sunspots, which are a primary source of solar flares and other solar disturbances. Time-Distance method will be used. Since the details in the near surface layers are important the highest resolution data will be needed. It is necessary to observe all phases of the lifetime of several delta-type spot (>5). With this coverage we should be able to determine the flow-evolution from prior to formation of delta-type configuration, and understand the mechanism of their formation. This may enable prediction of such spot. Since Time-Distance methods will be used gaps should be clumped into as few sub-intervals as possible. Ring type analyses do not give enough resolution for these studies.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
HS-8	OS-8	fd_V	Any	95%	Any	> 5 delta-type sunspots	1”	Need to sample several at all phases of their life

Observing Sequence Type OS-8 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-8	10d	95%	90s	clumped	

Observation Type MAG-1

Magnetic field distribution and evolution. This type of observation provides data to allow study on generation, distribution, evolution and dispersion of magnetic fields for short-term and long-term variations in both small and large scales. Observations of vector magnetic field and line-of-sight magnetic field over the whole solar disk, and the related synoptic maps are needed.

Observations need to cover whole rising phase: from solar min to max. 5 minutes average of magnetic field per hour should have sufficient temporary resolution with better signal to noise. We believe 10 hours data gap can still form synoptic maps with reasonable accuracy.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-1	OS-9	fd_**B** fd_B	Solar minimum to solar maximum	80%	3-years		2”	

Observing Sequence Type OS-9 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-9	3-years	80%	10 hours	random	

Observation Type MAG-2

Formation and deep structure of magnetic complexes. This type of observation supports analyses on both evolution and configuration of magnetic fields in active regions. The iteration techniques will be used to calculate non-linear force-free-field structures in active regions, and to help determine magnetic topology. The major effort for this investigation will be taken from Helioseismology. Observation for magnetic field will be consistent with that, which is to cover solar rising phase: from min to max.

Type	Observing Sequence Needed	Observables	Planned Span of Observations	Planned Number of Observations (percent coverage)	Minimum Span of Observations	Minimum Number of Observations (percent coverage)	Minimum Image resolution	Notes
MAG-2	OS-10	fd_**B** fd_B	Solar minimum to solar maximum	80%	3-years		2”	

Observing Sequence Type OS-10 Table Entry

Observing Sequence Type	Nominal Interval	Completeness in interval	Max harmless gap	Optimum Gap distribution	Notes
OS-10	3-years	80%	12 hours	random	

Observation Type MAG-3

Emerging magnetic flux studies. This type of observation supports both magnetic topology and plasma motion analyses, and also supports tracking whole process of magnetic flux emerging. The iteration methods and induction local correlation tracking will be used to derive magnetic fields in the corona in active regions and plasma flows on the photosphere. Extrapolation of coronal magnetic field from synoptic maps of line-of-sight magnetic field will be performed based on various models. The goal is to study whole process of emerging of magnetic flux, its magnetic topology, how it links with and interacts with pre-existing magnetic fields, and why that leads to occurrences of flares, CMEs and eruptions of filaments.

Usually vector magnetic field measurements with limited field of view miss the beginning phase of flux emerging, and also lack information for global magnetic content. We believe that vector magnetic field measurement over the whole solar disk can record flux emerging process from its very beginning to the end, and also provide necessary knowledge of couples of emerging flux regions (EFR) with pre-existing fields in both local scale and global scale.10-hour observational interval allows us to measure whole process of flux emerging. 10-minute cadence for vector field measurement and 1-minute cadence for line-of-sight field measurement make it possible to resolve the quick emerging of magnetic flux at its very beginning phase, and also allows us to derive plasma motion and to examine variation of magnetic topology. 1-arcsecond resolution will help determine fine structure of magnetic fields and locate solar transients in frame of magnetic field. We believe that measuring 100 emerging flux regions can form a sample containing a complete spectrum of emerging flux regions with various relations with solar transients. 100 active regions can be captured in about 2.5 year in solar minimum or in less than 6 months near solar maximum, and it is possible to measure 100 cases of emerging magnetic flux meanwhile.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-3	OS-11	fd_**B**, fd_B	5-years	100%	2.5-years starting at min or 1 year at max	100 emerging flux regions	1”	Emerging flux regions, Active Regions, filaments.

Observing Sequence Type OS-11 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-11	10 hours	100%	1 minute	random	

Observation Type MAG-4

Magnetic energy and instability in solar active regions. This type of observation supports both magnetic topology and plasma motion analyses. The iteration methods and induction local correlation tracking will be used to derive magnetic fields in the corona in active regions and plasma flows on the photosphere, and vector magnetic field maps will be used to demonstrate distribution of magnetic energy. In this way, both energy flux and helicity flux flowing through the photosphere will be estimated, which are essential for studies on buildup and development of magnetic energy and instability. 10-minute cadence is required to detect variation of magnetic fields due to emerging flux and solar transients, and to determine plasma flows using induction local correlation tracking. We will track disk passage of 100 active regions for 10 days per region. We believe that at least 5 delta-type sunspots will be included, which we consider is a basic sample for delta-type sunspot study.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-4	OS-12	fd_**B**	5-year	95%	2.5-years starting at min or 1 year at max	100 active regions containing at least 5 delta-spots	2”	Delta_type sunspots

Observing Sequence TypeOS-12 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-12	10d	95%	10 minutes	random	

Observation Type MAG-5

Solar flares and CMEs studies. This type of observation provides data to allow study for topology of magnetic fields, and buildup and development of magnetic energy and instability in solar corona. The iteration techniques for non-linear force-free field calculation will be used to reproduce coronal magnetic fields above the active regions, and the induction local correlation tracking will be employed to determine plasma motions on the photosphere. Various models based on synoptic maps of magnetic field will be used to extrapolate fields in global scale and in heliosphere.

Full disk magnetic field measurement with 10 minutes cadence allow the induction local correlation tracking technique performed to derive plasma flows on the surface. Combination of vector magnetic field and plasma flow information provides estimate of energy and helicity flux through the photosphere with a temporary resolution of 10 minutes. That enables us to resolve the emerging process of magnetic flux. Modeled non-linear force-free-field in the corona will demonstrate variation of topology with 10 minute resolution.

Line-of-sight magnetic field measurement with 1 minute cadence allows update of synoptic maps of magnetic field with 1 minute resolution. Consequently, magnetic fields in global and heliospheric scales will be modeled with such a resolution, so that the calculations will be used to reveal magnetic links and to detect transient-related changes.

A sample of 50 active regions with flares is expected to be collected after tracking 100 active regions. We believe this sample consists of flare-producing active regions that associate with CMEs. An interval of observation for 2 days will cover whole process of solar transients.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-5	OS-13	fd_**B** fd_B	5-year	95%	2.5-years starting at min or 1 year at max	50 active regions with flares	1”	Active regions

Observing Sequence Type OS-13 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-13	2d	95%	1 minute	random	

Observation Type MAG-6

Magnetic carpet studies. This type of observation supports analyses on both evolution and configuration of magnetic elements. One-minute full disk magnetograms for line-of-sight field is sufficient to determine evolution of magnetic elements. Elements generally have a lifetime of 50 hours. Vector magnetic field measurement with a cadence of 24 hours is needed to derive their magnetic configurations. Monthly observation will demonstrate global distribution and long-term evolution of magnetic elements. We should extend observation from solar minimum to solar maximum to examine their relations with transformation of the large scale fields.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-6	OS-14	fd_**B** fd_B	Solar minimum to solar maximum	95%	1-month		2”	Active regions

Observing Sequence Type OS-14 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-14	4d	95%	10 minutes	random	

Observation Type MAG-7

Studies for energetics and complexity of solar corona. This type of observation provides data to allow study for topology structure of magnetic field, and buildup and development of magnetic energy and instability in solar corona. The methods used and observation required are nearly identical to MAG-5, except samples accumulated.

The observational targets are solar active regions with various magnetic configurations and evolutionary characteristics. 100 active regions should be sufficient to include active regions from simple to complex configurations, and within them we believe there are comparable cases for emerging flux regions. As both long-term and short-term effects are suggested to buildup energy and lead to development of instability, we will track every active region during its disk passage so that observation interval is required to be 12 days.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-7	OS-15	fd_**B** fd_B	5-year	95%	2.5-years starting at min or 1 year at max	100 active regions	1”	Active regions

Observing Sequence Type OS-15 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-15	12d	95%	10 minute	random	

Observation Type MAG-8

Large-scale coronal fields and solar wind. This type of observation provides data to allow study on coronal field structures in large scale and their relations with solar wind and CMEs, and solar wind originated from solar active regions. Modeled coronal and heliospheric structures of magnetic fields from magnetic field synoptic maps will be used to demonstrate characteristics of magnetic fields in global scale, and the iteration techniques for non-linear force-free-field calculation will be employed to reveal magnetic structures in active regions and their links to large-scale fields.

3 sets of observation per day for full disk vector magnetic field or line-of-sight magnetic field are sufficient to show large-scale magnetic configuration computed from various models. This product is also used to reveal relationship with magnetic configurations and locations of occurrences of CMEs. Since reformation of streamers after CMEs could be as short as several ten minutes, investigation of changes of large-scale fields during CMEs needs higher cadence for observation. We believe 10 minutes cadence with 2 days interval for magnetic field observation should be sufficient.

Since magnetic configuration shows significant different patterns for solar minimum and maximum, we should extend observation covering whole solar rising phase.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
MAG-8	OS-16	fd_**B** fd_B	Min-max	80%		Several Carrigton rotations for solar min and solar max	2”	

Observing Sequence Type OS-16 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-16	2d	80%	10 minute	random	

Observation Type IC-1

Irradiance Sources Studies. This observation type produces data to allow study of variations of continuum intensity in the vicinity of the HMI spectral line. These data may be considered as a proxy for irradiance. These measurements require calibration of system pixel-pixel gain variations to a level 0.1% as demonstrated by MDI. Time-Distance methods will be used. The goal is to provide maps of intensity once per hour. The data will be averaged over 5-min interval. The irradiance studies should cover at least 3 years, from solar minimum to maximum.

Type	Observing Sequence Needed	Observables	Planned Span of Observations	Planned Number of Observations (percent coverage)	Minimum Span of Observations	Minimum Number of Observations (percent coverage)	Minimum Image resolution	Notes
IC-1	OS-17	Ic_fd	3-years	80%	3-years starting at min including 1 year at max	80%	2”	

Observing Sequence Type OS-17 Table Entry

Observing Sequence Type	Nominal Interval	Completeness in interval	Max harmless gap	Optimum Gap distribution	Notes
OS-17	5min/hour	80%	10 hours	random	

Observation Type IC-2

Delta-type Sunspot Studies. This observation type produces data to allow study of thermal structures and energy release events associated with formation and evolution of delta-type sunspots, which are a primary source of solar flares and other solar disturbances. Since the details in the near surface layers are important the highest resolution data will be needed. It is necessary to observe all phases of the lifetime of several delta-type spot (>5). With this coverage we should be able to determine the flow-evolution from prior to formation of delta-type configuration, and understand the mechanism of their formation. This may enable prediction of such spot. Since Time-Distance methods will be used gaps should be clumped into as few sub-intervals as possible. Ring type analyses do not give enough resolution for these studies.

Type	**Observing Sequence Needed**	**Observables**	**Planned Span of Observations**	**Planned Number of Observations (percent coverage)**	**Minimum Span of Observations**	**Minimum Number of Observations (percent coverage)**	**Minimum Image resolution**	**Notes**
IC-2	OS-18	fd_Ic	Any	95%	Any	> 5 delta-type sunspots	1”	Need to sample several at all phases of their life

Observing Sequence Type OS-18 Table Entry

Observing Sequence Type	**Nominal Interval**	**Completeness in interval**	**Max harmless gap**	**Optimum Gap distribution**	**Notes**
OS-18	10d	95%		clumped	

Table 4. Observation Types and Instrument Requirements

Observation types	Observable, object	Res	Precision	Accuracy	Noise	Cadence	Dynamic range	Primary use
HS-1	V, fd	2”	10 m/s		25m/s;1m/s disk aver.	50 s	±6.5km/s	Global Helioseismology
HS-2	V, fd	2”	10 m/s		25 m/s	50 s	±6.5km/s	Global Scale Local Helioseismology
HS-3	V, fd	2”	10 m/s		25 m/s	50 s	±6.5km/s	Sub-Surface Solar Weather
HS-4	V, ARs	2”	10 m/s		25 m/s	50 s	±6.5km/s	Active Longitudes
HS-5	V, ARs	1”	10 m/s		25 m/s	50 s	±6.5km/s	Active Regions
HS-6	V, fd	2”	10 m/s		25 m/s	50 s	±6.5km/s	Irradiance Sources
HS-7	V, fd	2”	10 m/s		25 m/s	50 s	±6.5km/s	Far-Side Imaging
HS-8	V, ARs	1”	10 m/s		25 m/s	50 s	±5.5km/s	Delta-type sunspots
MAG-1	B&**B**-5m, fd	2”	0.3%(polarization)	0.3G	7G/5min	300s	±4kG	Magnetic Field Distribution and Evolution
MAG-2	B&**B** -5m, fd	2”	0.3%(polarization)		7G/5min	300s	±4kG	Magnetic Complexes
MAG-3	B&**B**, ARs	1”	0.3%(polarization)		17G/50s	50s(B) 600s(**B**)	±4kG	Emerging Flux
MAG-4	B&**B**, ARs	1”	0.3%(polarization)		17G/50s	50s(B) 600s(**B**)	±4kG	Energy and Instabilities in AR
MAG-5	B&**B**, ARs	1”	0.3%(polarization)		17G/50s	50s(B) 90-100s(**B**)	±4kG	Flares and CMEs
MAG-6	B, fd	2”	0.3%(polarization)	0.3G	17G/50s	50s	±4kG	Magnetic Carpet
MAG-7	B&**B**,fd	1”	0.3%(polarization)	0.3G	7G/5min	300s	±4kG	Energetics and Complexity of Corona
MAG-8	B or **B**, fd	2”	0.3%(polarization)		7G/5min	8h	±1kG	Large-Scale Corona and Wind
IC-1	Ic,fd	2”	0.1% flat f.		0.3%	50s		Irradiance Sources
IC-2	Ic,fd	1”	0.1% flat f.		0.3%	50s		Delta-type Sunspots

Table 5. Instrument Requirements Summary

Observation types	Observable, object	Res	Precision	Accuracy	Noise	Cadence	Dynamic range	Primary use
HS-1 – HS-8	V, fd	1-2”	10 m/s		25m/s 1m/s disk aver.	50 s	±6.5km/s	Global and Local Helioseismology
MAG-1-MAG-8	B&**B**, fd	1-2”	0.3%(polarization)	0.3G (zero point)	17G in 50sec	50s(B) 90-100s (**B**)	±4kG	Magnetic Field Objectives
IC-1-IC-2	Ic,fd	1-2”	0.1% flat field		0.3%	50s		Irradiance Sources

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